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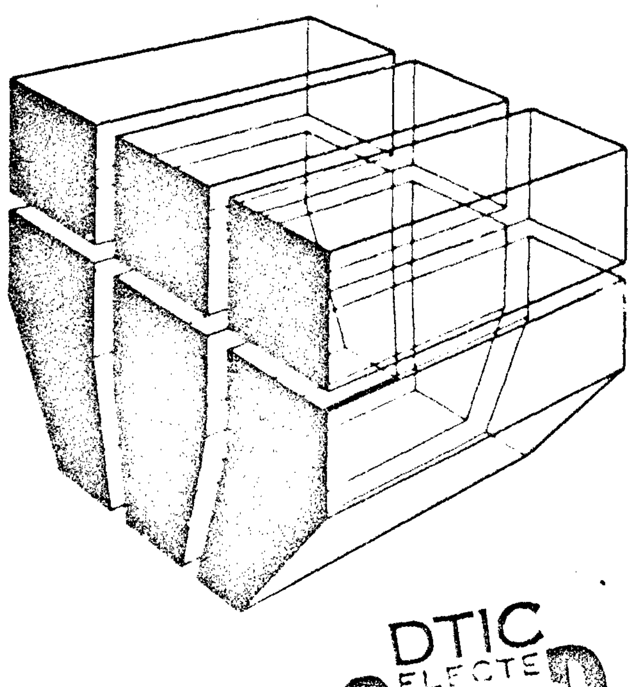
of Engineers
Construction Engineering
Research Laboratory

TECHNICAL REPORT M-338
December 1983

12

MUNITIONS STORAGE CONCEPTS
FOR USE IN FLAT TERRAIN:
VOLUME II, MUNITIONS STORAGE LAYOUTS



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weapons
storage
magazines (ordnance)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this project was to develop feasible concepts for weapon storage facilities located in flat terrain with a high water table. The result of the study is preliminary design of six feasible storage complexes. Both aboveground and underground structures are proposed. The special construction practices necessitated by the high water table are addressed. Each design is capable of containing the hazardous effects of an internal explosion within the bay of occurrence. The facilities are

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also designed to survive such external threats as detonation of 300,000 pounds of high explosive 100 meters away from the structure, a direct hit by a 500 pound bomb, a B747 aircraft impact on the roof, and a sophisticated terrorist attack. Furthermore, under chemical warfare conditions, the facilities can continue the weapon loadout process while maintaining a clean environment within the structure. Twenty-five year life cycle cost estimates are included for each of the six designs.

Volume I contains a narrative description of the evolutionary design process that led to the six proposed designs, a technical discussion of the design constraints imposed by the various threat scenarios, and a detailed description of the six facility designs. Volume II documents the engineering calculations supporting the structural designs and the life cycle cost calculations. Plan and section drawings are provided for each of the six facilities.

FOREWORD

This research was conducted for the Defense Nuclear Agency (DNA) by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (CERL) under DNA RDT&E funds for FY 1982, Task Code A99QAXFC. The study was prepared for CERL by the Southwest Research Institute, San Antonio, TX, under DACA88-82-C-0013. Dr. Anthony Kao was the CERL Contract Project Officer. MAJ L. T. Messenger was the DNA Technical Monitor.

The authors would particularly like to thank Messrs. Ken Morrison, Leonard Carthon, E. Jerry Dietrich and James Saylors of Bernard Johnson, Inc., for their work and input during this project. Jarvis Michie, Norma Sandoval, Trish Moseley, Luis Garza, Jack Riegel, and Don Ketchum of SWRI are acknowledged for their contributions to this project, as are Sue Lindsay, Lynette Ramon, Deborah Stowitts, and Joe Cardinal for the preparation and editing of this report.

Dr. R. Quattrone is Chief of CERL-EM. COL Paul Theuer is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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APPENDIX 1

MUNITIONS STORAGE LAYOUTS

PRELIMINARY LAYOUTS AND EVALUATIONS SUMMARIES

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: mob DATE: ____ 19 ____ CHECKED BY: MW DATE CHECKED: ____ 19 ____

1 • TOTAL FLOOR AREA (H)

2 • OPER. EFFIENCY
2a - BAY - MAIN - BAY (L)
2b - LOADOUT (M) FL = 10 CR = 7

3 • EXPANDABILITY (L)

4 • LOAD DOCK SEPARATION (H) <150' = 0 >150' = 10 opp side = 10

5 • PERIMETER WALL AREA/Vol. (M)

6 • BAY INTERIOR WALL AREA/Vol. (H)

7 • "SQUARENESS" OF S, M, L & C (M)

8 • QUANTITY OF BLAST DOORS (L) 5 Doors = 10 ; 6 Doors = 9 etc

9 • WEAPONS BAY LOCATION (L) (INT/EXT) Ext = 8 , Int = 10

10 • QUANTITY OF MAINT. BAYS (H) 1 Bay = 10, 2 Bays = 5

11 • EQUIPMENT NEEDS (H)
- BASE NEEDS 2 Forel = 10 2 Fel + 2 Cree 7
- Pre [illegible]: Fe = 10 : Ce = 0
- P[illegible] Pits Fe = 10 , Ce = 7

MULTIPLIERS:
H = 3 (HIGH)
M = 2 (MEDIUM)
L = 1 (LOW)
PRIORITY

CEILING HT.
Avg Wall = 10'
PAC-MAN = 15'
Pits = 15'

FLOOR AREA RANKING:		EXTERIOR AREA		INT. AREA
30 - 32.5K	= 10	8160 - 8680	= 10 :	5000 - 5500
32.5 - 35	= 9	8680 - 9200	= 9 :	5500 - 6000
35 - 37.5	= 8	9200 - 9732	= 8 :	6000 - 6500
37.5 - 40	= 7	9732 - 10260	= 7 :	6500 - 7000
40 - 42.5	= 6	10260 - 10780	= 6 :	7000 - 7500
42.5 - 45	= 5	10780 - 11304	= 5 :	7500 - 8000
45 - 47.5	= 4	11304 - 11828	= 4 :	8000 - 8500
47.5 - 50	= 3	11828 - 12352	= 3 :	8500 - 9000
50 - 52.5	= 2	12352 - 12900	= 2 :	9000 - 9500
52.5 - 55	= 1	12900 - 13400	= 1 :	9500 - 10000
55 → ∞	= 0	13400 →	= 0 :	10000 →

SOUTHWEST RESEARCH INSTITUTE
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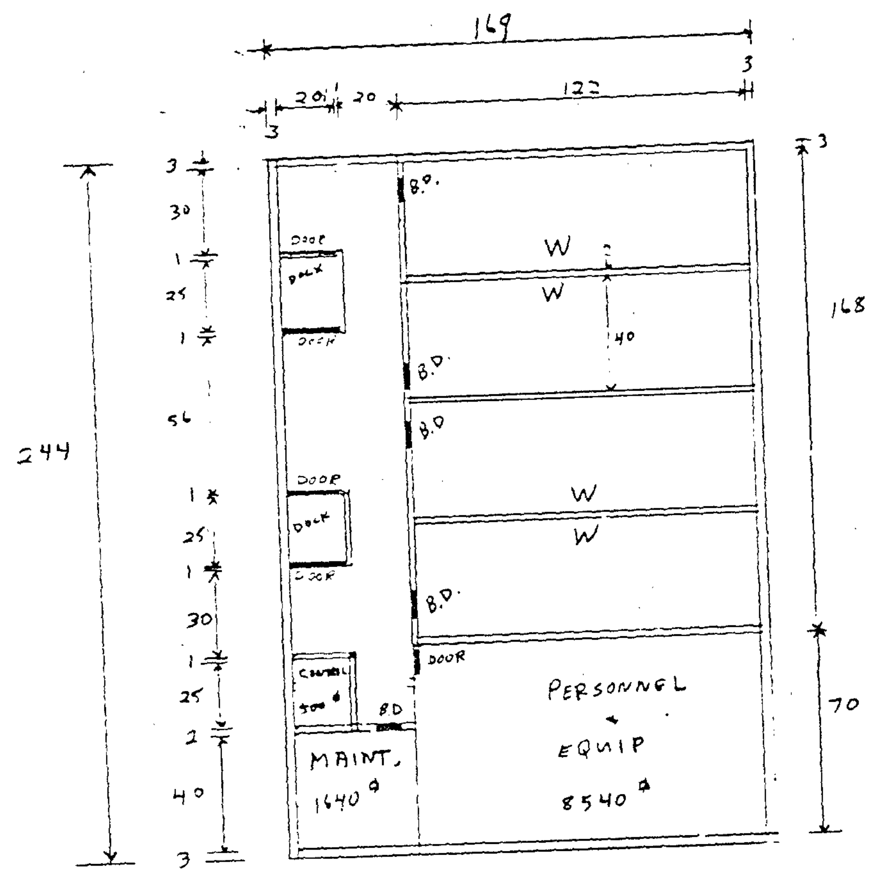
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: B. MORRIS DATE: 8 JUL 1982 CHECKED BY: nwb DATE CHECKED: ____ 19 ____



BLAST DOOR No. = 5

W = 4800 ft²/ea
S = 8540 ft²
M = 1640 ft²
L = 500 ft²/ea
C = 500 ft²
TOTAL AREA = 41,236 ft²
EXTERIOR AREA = 8260 ft²
INTERIOR AREA = 7210 ft²

DESIGN 1-1
120X40 BAY

SOUTHWEST RESEARCH INSTITUTE
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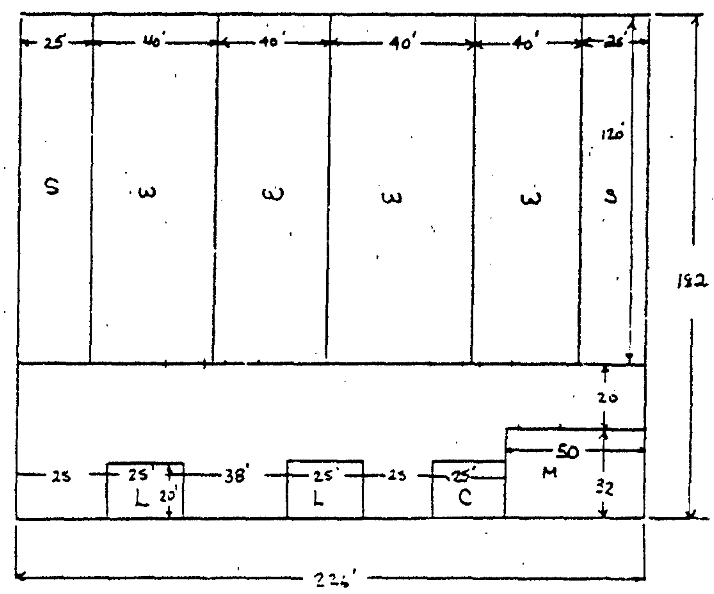
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: LMV DATE: ____ 19 ____ CHECKED BY: mot DATE CHECKED: ____ 19 ____



W = 4800 ft²/ea
S = 6000 ft²
M = 1600 ft²
L = 500 ft²/ea
C = 500 ft²/ea
TOTAL AREA = 41132 ft²
EXTERIOR WALL = 8160 ft²
INTERIOR WALL = 8420 ft²
BLAST DOOR NO = 5

DESIGN 1-2
120x40 BAY

SOUTHWEST RESEARCH INSTITUTE
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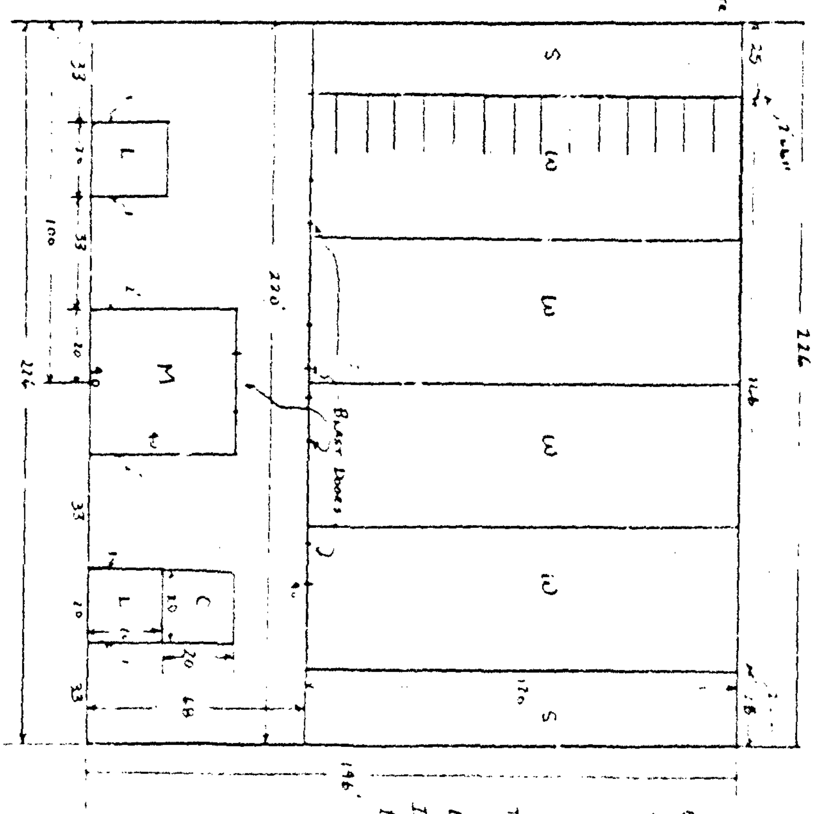
COMPUTATION SHEET

SHEET NO ____ OF ____

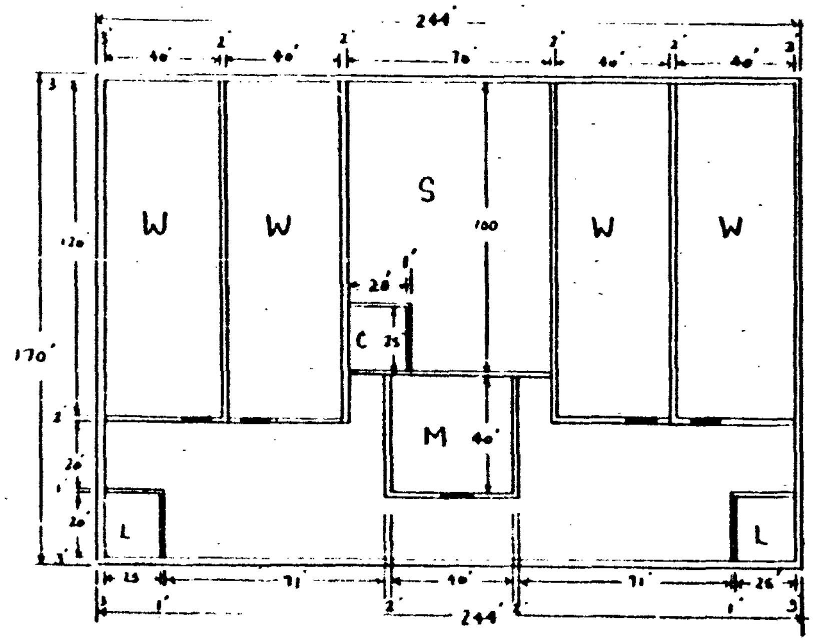
PROJECT NO 02-7092 SPONSOR CERL
SUBJECT LAYOUT
BY ______ DATE ______ 19 ___ CHECKED BY ______ DATE CHECKED ______ 19 ___

Dividing Walls - 1 ft Concrete
Each Bay is 7 ft Wide



Sq Footage (Interior)
W 4400 ea
M - 1600
L - 400 ea
C = 400
Total Area Interior
44296 ft²
Interior Wall = 9800 ft²
Blast Door No = 7
120 X 40 BAY

Design - 1 - 3.



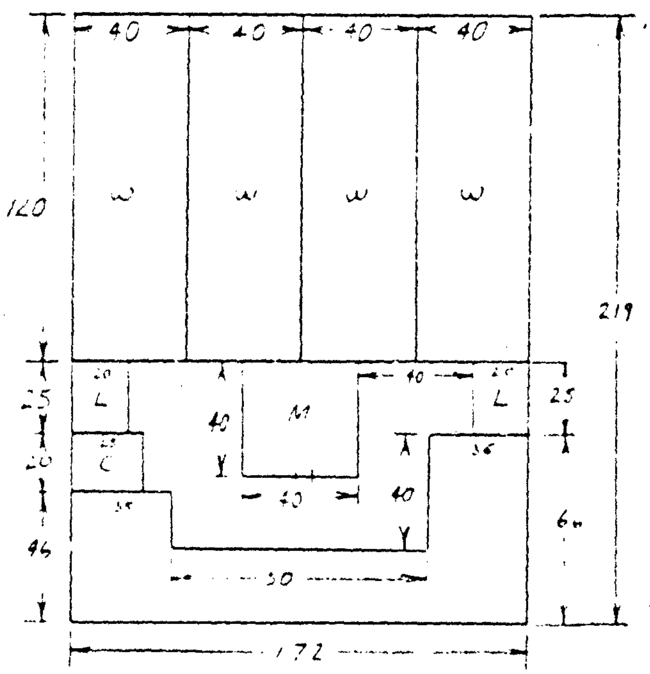
C = 500 ft²
L = 500 ft²/ea
S = 6454 ft²
M = 1600 ft²
W = 4800 ft²/ea
Total Area = 41,480 ft²
Exterior Wall = 8280 ft²
Interior Wall = 8000 ft²
No. Blast Doors = 5

Design No 1-4
Ranking 283

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MVV DATE: ____ 19 ____ CHECKED BY: [signature] DATE CHECKED: ____ 19 ____



W = 4500 ft²/ea
S = 6416 ft²
M = 1600 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area = 37 700 ft²
Exterior Wall = 7820 ft²
Interior Wall = 6400 ft²
Blast Door No = 5
20 x 40 Bay

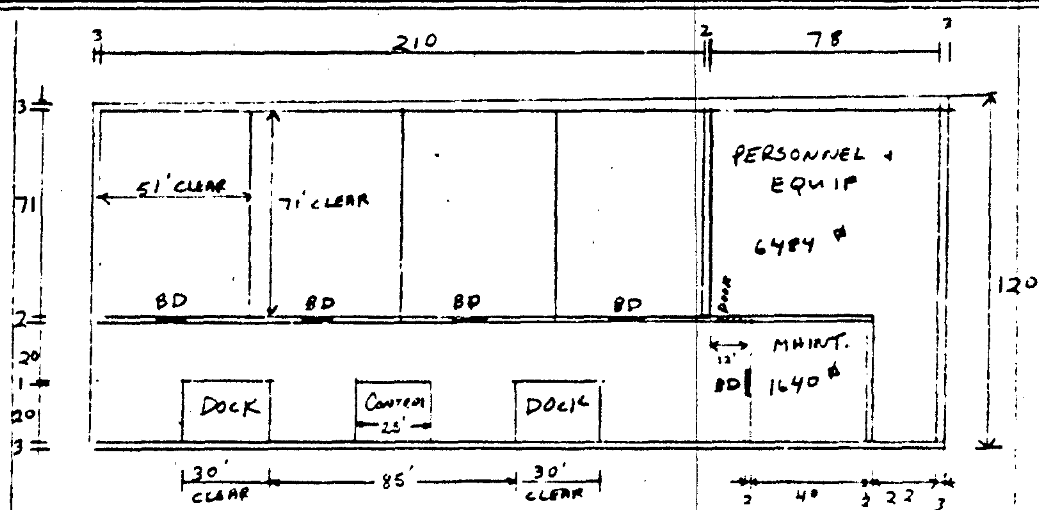
1-7

Design 1-5

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO ______ OF ______

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT - 51' x 71' INTERIOR BAY
BY: B. MORRIS DATE: 13 JUL 19 83 CHECKED BY: MWT DATE CHECKED: ______ 19 ______



W = 3621 ft²/ea
S = 6484 ft²
M = 1640 ft²
L = 600 ft²/ea.
C = 500 ft²/ea
Total Area = 35,520 ft²
Exterior Wall = 12480 ft²
Interior Wall 9150 ft²
Blast Door No. = 5

DIVIDING WALL BAY

DESIGN 1-6

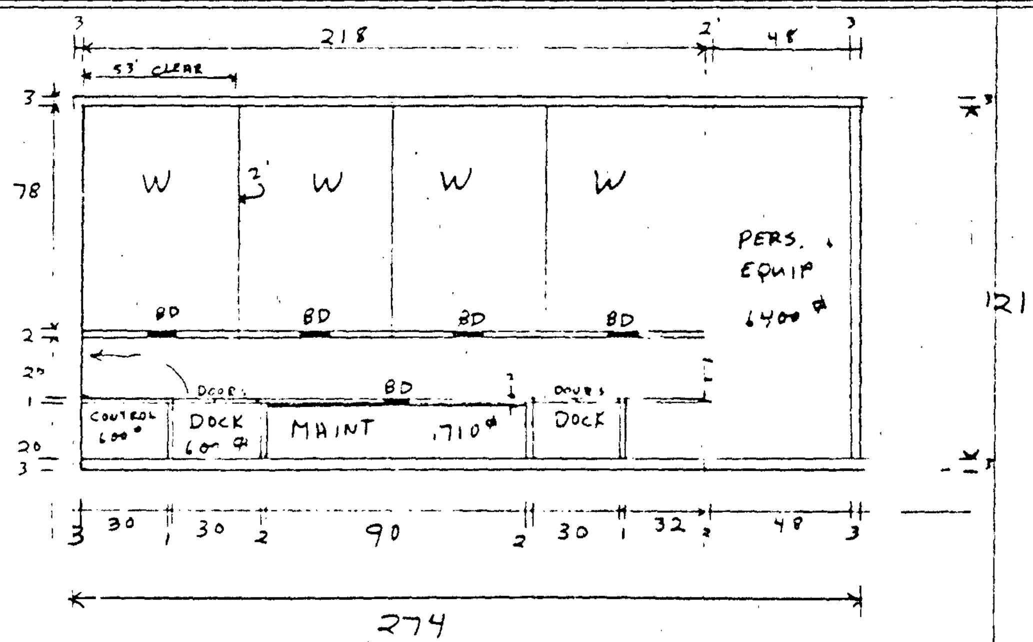
SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT: LAYOUT USING 78 X 53' BAYS

BY: E. MORRIS DATE 12 July 83 CHECKED BY: [signature] DATE CHECKED: ____ 19 ____



$W = 4134$ ft²/ea

$S = 6400$ ft²

$M = 1710$ ft²

$L = 600$ ft²/ea

$C = 600$ ft²

Total Area = 34,798 ft²

Exterior Wall = 12030 ft²

Interior Wall = 9810 ft²

Blast Door No = 5

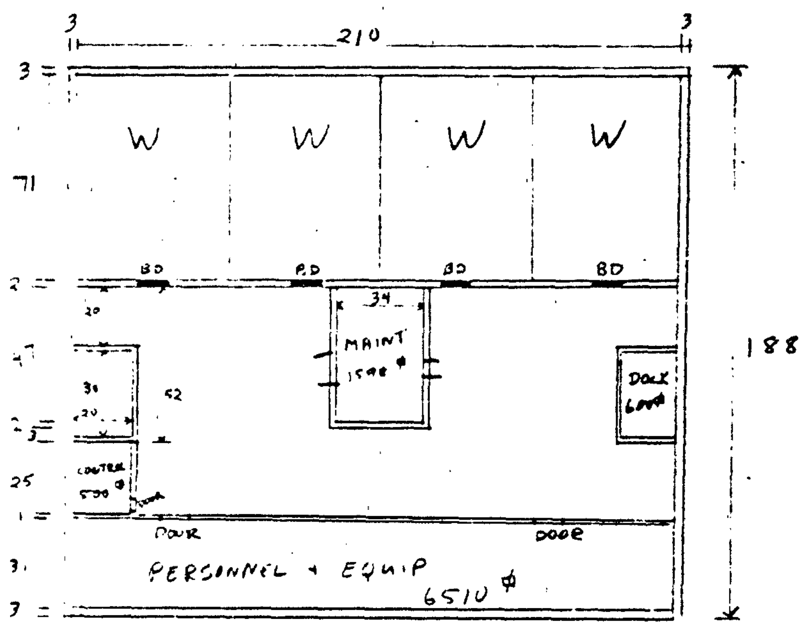
[illegible] WALL BAY

Design 1-7

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT - 51' x 71' INTERIOR BAYS
BY: E. MORRIS DATE: 13 Jun 19 82 CHECKED BY: [illegible] DATE CHECKED: ____ 19 ____



W = 3621 ft²

B = 6510 ft²

M = 1598 ft²

L = 600 ft²/ea

C = 500 ft²

TOTAL AREA = 39,480 ft²

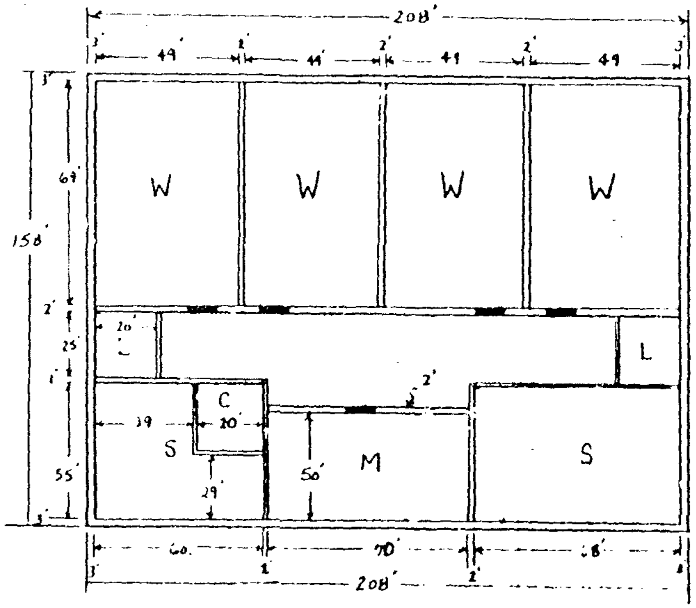
EXTERIOR WALL = 12120 ft²

INTERIOR WALL = 8175 ft²

BLAST DOOR No = 5

DIVIDING WALL BAY

DESIGN 1-B



C = 500 ft²

L = 500 ft²/ea

S = 6494 ft²

M = 3500 ft²

W = 3381 ft²/ea

- Total Area = 32864 ft²
- Exterior Wall = 10980 ft²
- Int. Bay Wall = 8325 ft²

Blast Door No = 5

PIT BAY

Design No. 1-9

Ranked 228

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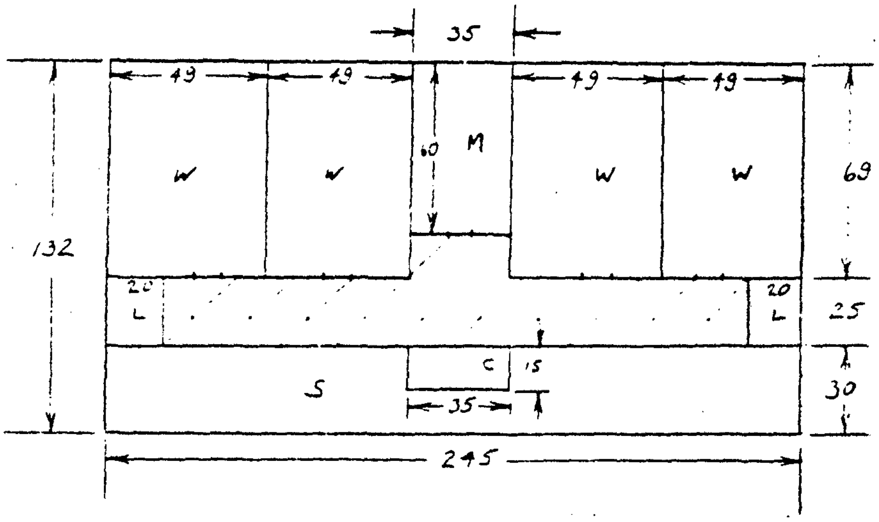
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ______ 19 ______ CHECKED BY: mwb DATE CHECKED: ______ 19 ______



$W = 3870\ ft^2/ea$

$S = 6825\ ft^2$

$M = 2100\ ft^2$

$L = 500\ ft^2/ea$

$C = 525\ ft^2$

TOTAL AREA = $32,300\ ft^2$

EXTERIOR WALL = $11,310\ ft^2$ (15' TALL)

INTERIOR WALL = $7605\ ft^2$

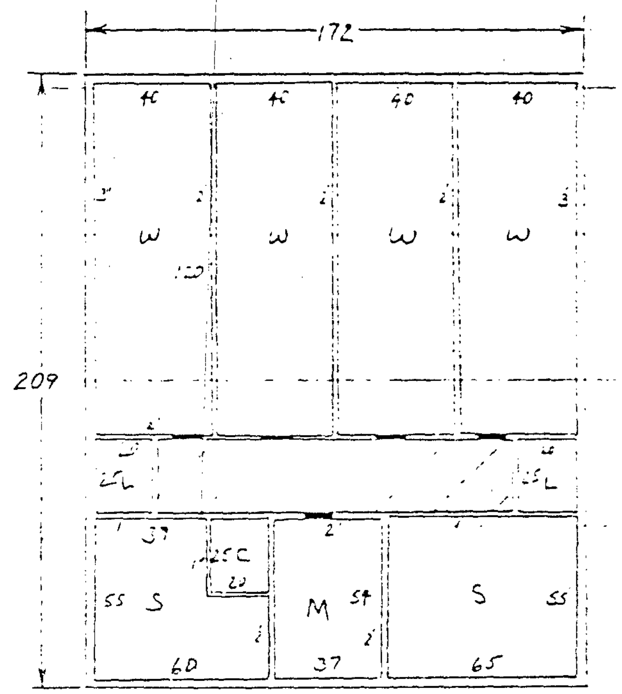
BLAST DOOR No. = 5

PIT BAY

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. C2-7092 SPONSOR. CERL
SUBJECT LAYOUT
BY. M.V. DATE. ____ 19 ____ CHECKED BY: mwb DATE CHECKED: ____ 19 ____



Below Ground.

W = 4800 ft²/ea
S = 6239 ft²
M = 1998 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area 35998 ft²
Perimeter Wall = 7820 ft²
Interior Wall = 6650 ft²
Blast Door No = 5

Design 1-11

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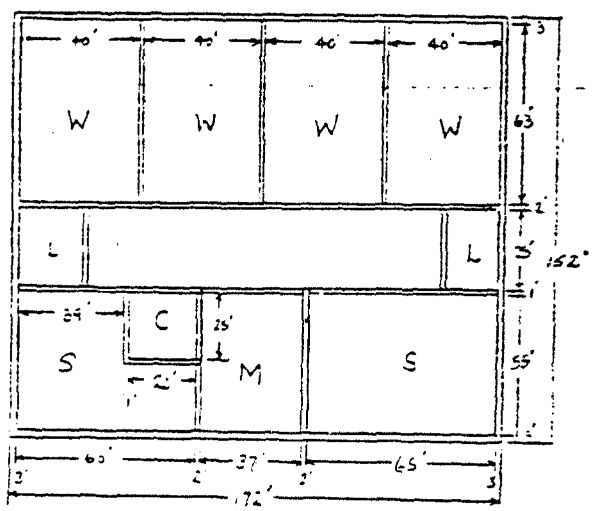
SHEET NO. ____ OF ____

PROJECT NO: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ______ 19 ____ CHECKED BY: nwb DATE CHECKED: ______ 19 ____



$W = 2520 \ ft^2/ea$
$S = 6329 \ ft^2$
$M = 2035 \ ft^2$
$L = 500 \ ft^2/ea$
$C = 500 \ ft^2$
Total Area : $26144 \ ft^2$
Interior Wall = 6705 (15' High)
Exterior Wall = 9720 (15' High)

Design 1-1.2

Option 3. Stacked Munitions

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COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: mwb DATE: ______ 19 ____ CHECKED BY: MW DATE CHECKED: ______ 19 ____

		1-1		1-2		1-3		1-4	
1 •	Total Floor Area (H)	6	18	6	18	5	15	6	18
2 • 2a	Oper. Efficiency – Bay-Main-Bay (L)	5	5	5	5	10	10	7	7
2b	– Loadout (H)	10	30	10	30	10	30	10	30
3 •	Expandability (L)	5	5	10	10	10	10	10	10
4 •	Load Dock Separation (H)	10	30	10	30	10	30	10	30
5 •	Perimeter Wall Area/Vol. (M)	10	20	10	20	10	20	10	20
6 •	Bay Interior Wall Area/Vol. (M)	6	12	4	8	3	6	5	10
7 •	"Squareness" of S.M. L & C (M)	10	20	2	4	2	4	10	20
8 •	5 Doors = 10; 6 Doors = 9 Quantity of Blast Doors (L)	10	10	10	10	10	10	10	10
9 •	Ext = 8, Int = 10 Weapons Bay Location (L) (Int-Ext)	8	8	8	8	8	8	8	8
10 •	1 Bay = 10, 2 Bays = 5 Quantity of Maint. Bays (H)	10	30	10	30	10	30	10	30
11 •	Equipment Needs (H) – Base Needs 2 Fixed = 10, 1 Fixed + 1 Free = 7	10	30	10	30	10	30	10	30
	– Permanency Fixed 10, Free	10	30	10	30	10	30	10	30
	– Pipe Penetrations Fixed 10, Free 7	10	30	10	30	10	30	10	30
			278		263		263		283

MULTIPLIERS:

H = 3
M = 2
L = 1

CEILING HT.
Ave Wall = 10'
PAC-MAN = 15'
Pits = 15'

FLOOR AREA RANKING:	
30 - 32.5K	= 10
32.5 - 35	= 9
35 - 37.5	= 8
37.5 - 40	= 7
40 - 42.5	= 6
42.5 - 45	= 5
45 - 47.5	= 4
47.5 - 50	= 3
50 - 52.5	= 2
52.5 - 55	= 1
55 → ∞	= 0

EXTERIOR AREA		INT. AREA
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible] DATE: ____ 19 ____ CHECKED BY: [illegible] DATE CHECKED: ____ 19 ____

		1-5		1-6		1-7		1-8	
1	Total Floor Area (H)	7	21	8	24	9	27	7	21
2	Oper. Effiency								
2a	- Bay-Main-Bay (L)	7	7	6	6	10	10	10	10
2b	- Loadout (H)	10	30	7	21	7	21	7	21
3	Expandability (L)	10	10	5	5	5	5	10	10
4	Load Dock Separation (H)	10	30	10	30	10	30	10	30
5	Perimeter Wall Area/Vol. (M)	10	20	2	4	3	6	3	6
6	Bay Interior Wall Area/Vol. (M)	8	16	2	4	1	2	4	8
7	"Squareness" of S M. L. & C (M)	4	8	8	16	4	8	8	16
8	5 Doors = 10 ; 6 Doors = 9 Quantity of Blast Doors (L)	10	10	10	10	10	10	9	9
9	Ext = 8 ; Int = 10 Weapons Bay Location (L) (Int/Ext)	8	8	8	8	8	8	8	8
10	1 Bay = 10, 2 Bays = 5 Quantity of Maint. Bays (H)	10	30	10	30	10	30	10	30
11	Equipment Needs (H)								
	- Base Needs 2 Floors = 10 [illegible] 7	10	30	7	21	7	21	7	21
	- Pr[illegible] Fx[illegible] : C[illegible]	10	30	0	0	0	0	0	0
	- Pac Regts Fx[illegible] : C[illegible] 7	10	30	7	21	7	21	7	21
			280		200		199		211

Multipliers:
H = 3
M = 2
L = 1

Ceiling Ht.
Ave Well = 10'
Pac-Man = 15'
Pits = 15'

Floor Area Ranking:		Exterior Area		Int. Area
30 - 32.5K	= 10	8160 - 8680	= 10 =	5000 - 5500
32.5 - 35	= 9	8680 - 9200	= 9 =	5500 - 6000
35 - 37.5	= 8	9200 - 9732	= 8 =	6000 - 6500
37.5 - 40	= 7	9732 - 10260	= 7 =	6500 - 7000
40 - 42.5	= 6	10260 - 10780	= 6 =	7000 - 7500
42.5 - 45.	= 5	10780 - 11304	= 5 =	7500 - 8000
45 - 47.5	= 4	11304 - 11828	= 4 =	8000 - 8500
47.5 - 50	= 3	11828 - 12352	= 3 =	8500 - 9000
50 - 52.5	= 2	12352 - 12900	= 2 =	9000 - 9500
52.5 - 55	= 1	12900 - 13400	= 1 =	9500 - 10000
55 → ∞	= 0	13400 →	= 0 =	10000 →

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COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CER
SUBJECT: LAYOUT
BY: mwb DATE: ____ 19 ____ CHECKED BY: MW DATE CHECKED: ____ 19 ____

		1-9		1-10		1-11		1-12	
1	Total Floor Area (H)	10	30	10	30	8	24	10	30
2	Oper. Effiency								
2a	- Bay-Main-Bay (L)	10	10	6	6	10	10	10	10
2b	- Loadout (H) Forklift - 10	7	21	7	21	10	30	10	30
3	Expandability (L)	9	9	10	10	9	9	10	10
4	Load Dock Separation (H)	10	30	10	30	10	30	10	30
5	Perimeter Wall Area/Vol (M)	5	10	4	8	10	20	[illegible]	[illegible]
6	Bay Interior Wall Area/Vol. (M)	4	8	5	10	7	14	7	14
7	"Squareness" of S.M. L&C (M)	10	20	3	6	10	20	10	20
8	Quantity of Blast Doors (L) 5 Doors = 10; 6 Doors = 9	10	10	10	10	10	10	10	10
9	Weapons Bay Location (L) (Int/Ext) Ext = 8, Int = 10	8	8	8	8	8	8	8	8
10	Quantity of Maint. Bays (H) 1 Bay = 10, 2 Bays = 5	10	30	10	30	10	30	10	30
11	Equipment Needs (H)								
	- Base Needs 2 Forks = 10, 2 Fork+2crk = 7	7	21	7	21	10	30	10	[illegible]
	- Pre-[illegible] Fork + Crane	0	0	0	0	10	[illegible]	[illegible]	30
	- Pit Preps Fork + Crane = 7	7	21	7	21	10	[illegible]	[illegible]	30
			228		211		294		298

MULTIPLIERS:
H = 3
M = 2
L = 1

CEILING HT.
Ave Wall = 10'
PAC-MAN = 15'
Pits = 15'

FLOOR AREA RANKING:

30 - 32.5K	= 10
32.5 - 35	= 9
35 - 37.5	= 8
37.5 - 40	= 7
40 - 42.5	= 6
42.5 - 45	= 5
45 - 47.5	= 4
47.5 - 50	= 3
50 - 52.5	= 2
52.5 - 55	= 1
55 → ∞	= 0

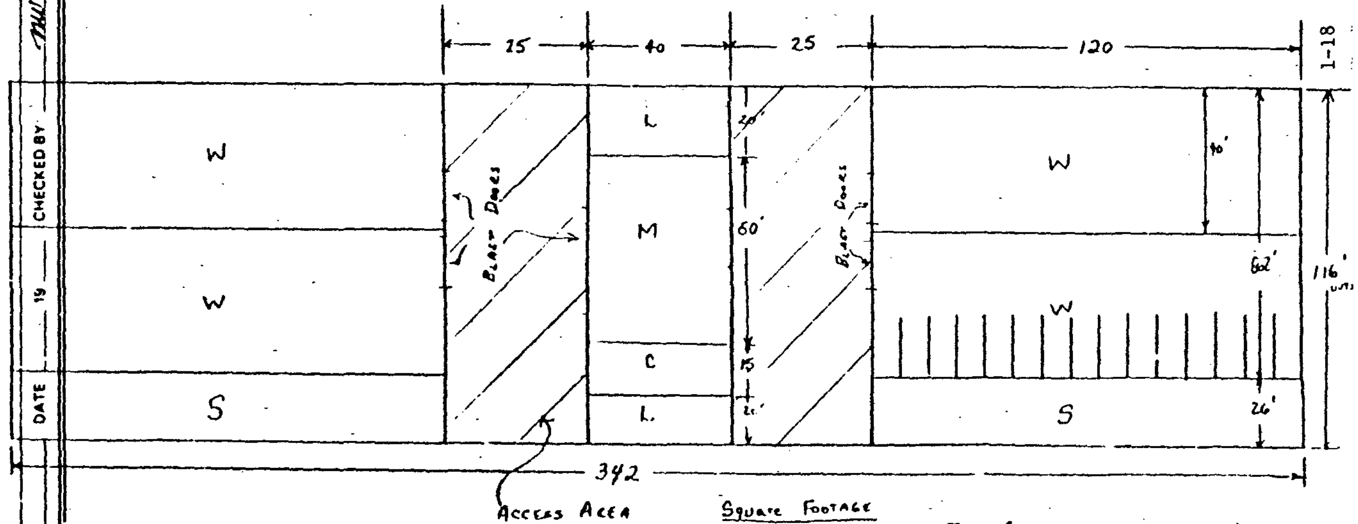
Exterior Area		Int. Area
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT:
BY: LMV DATE ____ 19 ____ CHECKED BY: MWB DATE CHECKED: ____ 19 ____

Dividing Walls = 1 ft Concrete
Each Bay is 70 ft Wide



Square Footage
W: 4800/ea (4)
S: 3120 ea (2)
M = 2000
L = 800/ea
C = 600

Total Area: 39672 ft²
Exterior Wall = 9160 ft²
Interior Wall = 9200 ft²
Blast Door No = 6
120x90 Bay

Design 2-1

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO ____ OF ____

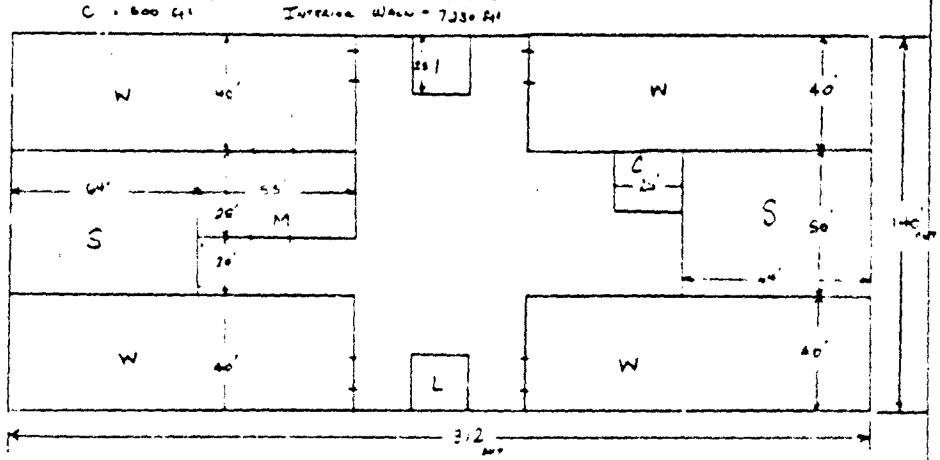
PROJECT NO 02-7072-001 SPONSOR CERL
SUBJECT LAYOUT
BY MV DATE ____ 19__ CHECKED BY mb DATE CHECKED ____ 19__

W = 4900 ft²/ea
S = 3200 ft²/ea
M = 1500 ft²
L = 500 ft²/ea
C = 600 ft²

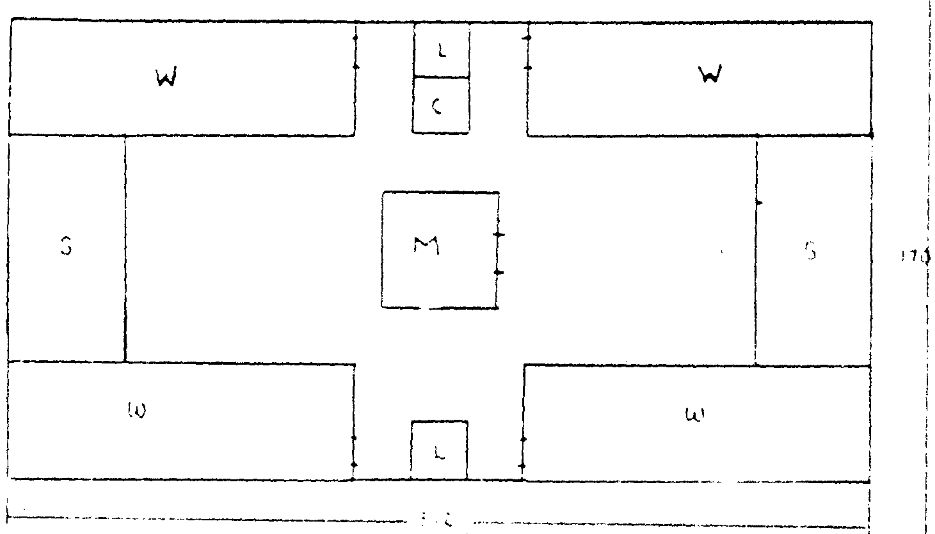
Access =
Total Area = 43680 ft²
Blast Doors = 5 or 6
Exterior Wall = 9040 ft²
Interior Wall = 7330 ft²

Design
2-2

Design - 10A



Design - 10



W = 4900 ea (4)
S = 3200 ea (2)
M = 1600
L = 500 ea (2)
C = 500

Access =
Total Area = 53040 ft²
Blast Doors = 5
Exterior Wall = 9600 ft² 1-19
Interior Wall = 7000 ft²

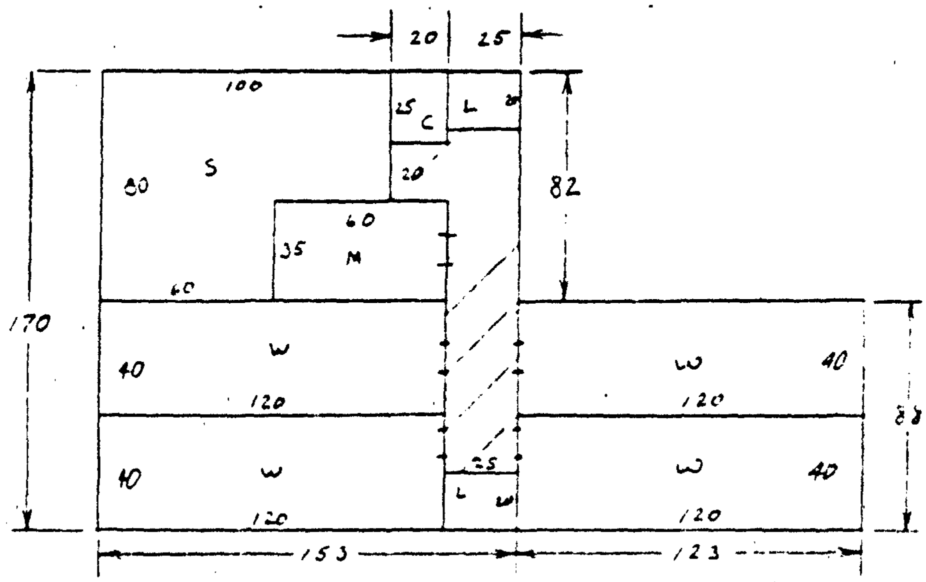
2-3

53040 ft²

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ____ 19 ____ CHECKED BY: mwb DATE CHECKED: ____ 19 ____



W = 4800 ft²/ea
S = 6600 ft²
M = 2100 ft²
L = 500 ft²/ea
C = 500 ft²

Total Area = 36,800 ft²
Exterior Wall = 8920 ft²
Interior Wall = 6500 ft²
Blast Door No = 5

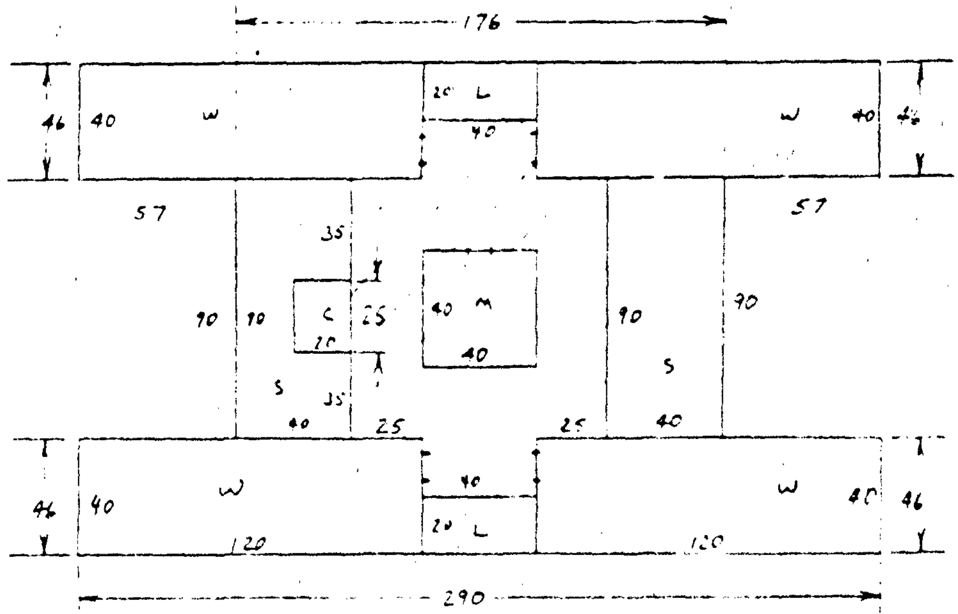
120 × 40 Bay

Design 2-4

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT: LAYOUT
BY: MW DATE ____ 19 ____ CHECKED BY: [illegible] DATE CHECKED ____ 19 ____



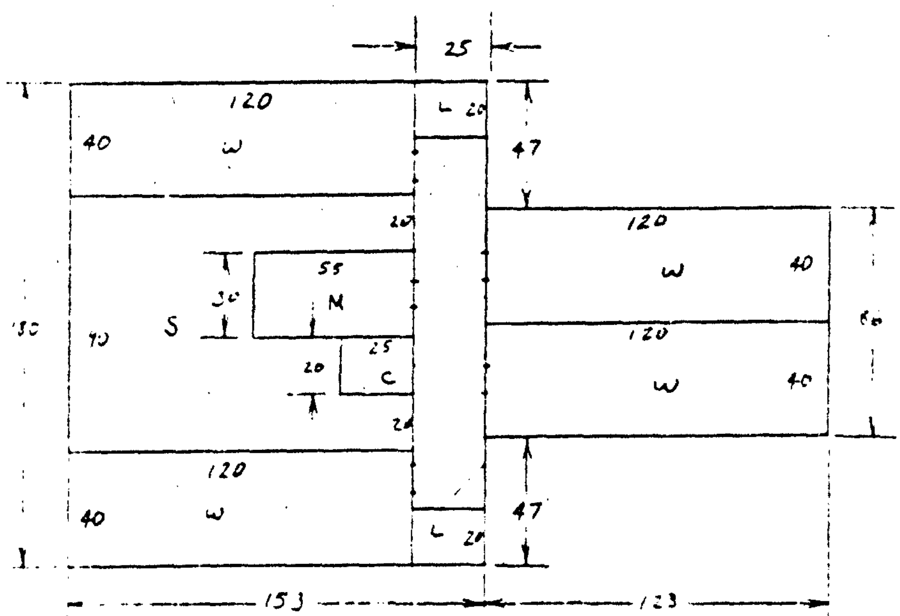
W = 4800 ft²/ea
S = 6700 ft²
M = 1600 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area = 42,500 ft²
Exterior Wall = 9440 ft²
Interior Wall = [illegible] ft²
Plant Door No = 5
20 x 20 [illegible]

Design 2-5

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ____ 19 ____ CHECKED BY: ____ DATE CHECKED: ____ 19 ____



W = 4800 ft²/ea

S = 6400 ft²

M = 1650 ft²

L = 500 ft²/ea

C = 500 ft²

Total Area = 38,100 ft²

Exterior Wall = 9120 ft²

Interior Wall = 10,350 ft²

120×40 Bay

Blast Door No = 5

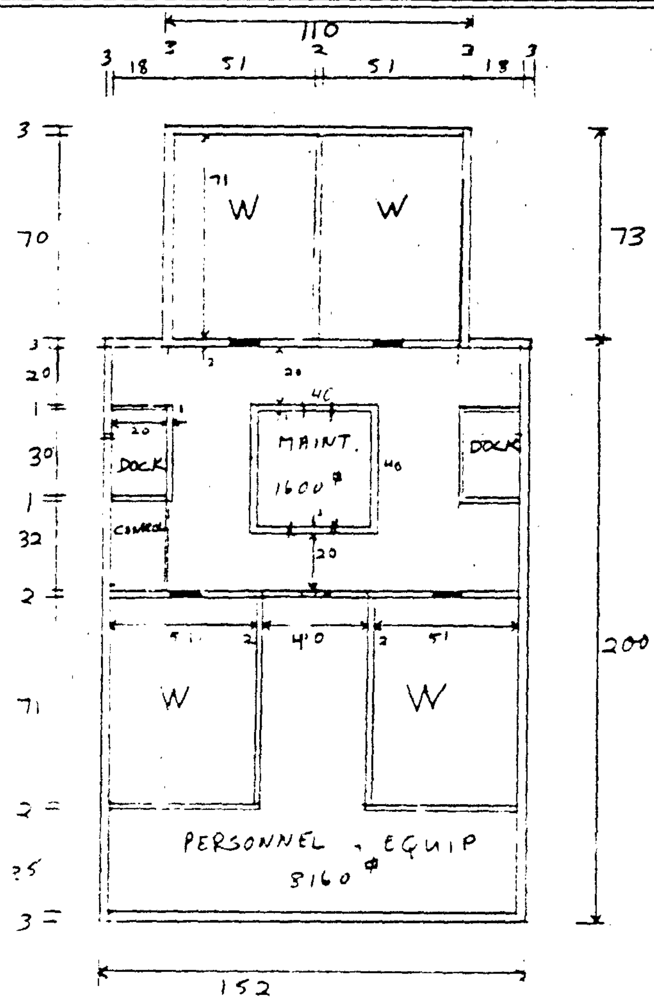
Design 2-6

1-22

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT – 51' X 71' INTERIOR BAY
BY: B. MORRIS DATE ____ 19 ____ CHECKED BY: [illegible] DATE CHECKED ____ 19 ____



W = 3621 ft²/ea
S = 8160 ft²
M = 1600 ft²
L = 600 ft²/ea
C = 640 ft²
TOTAL AREA = 38430 ft²

L A l 15' mod

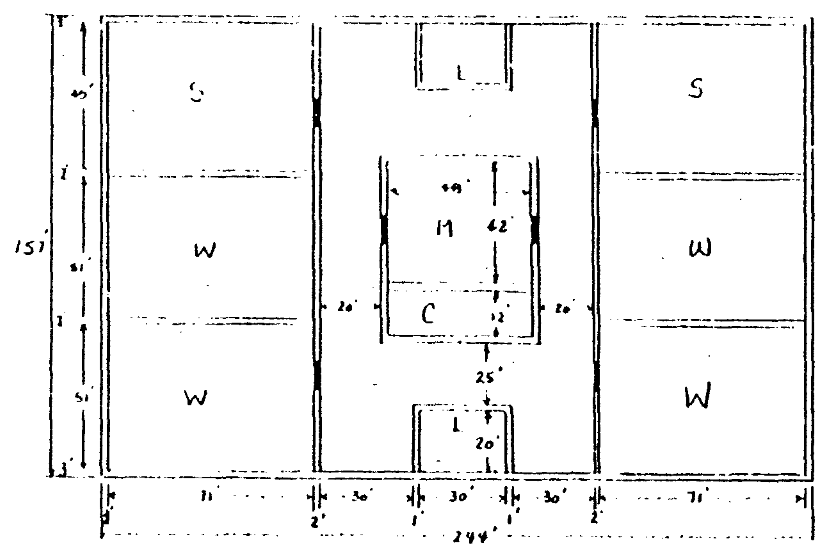
[illegible] = 850, 12750

[illegible] = 679, 10,185

DIVIDING WALL BAY

.-23

DESIGN 2-7



Below Ground 30'

PAC MAN DESIGN

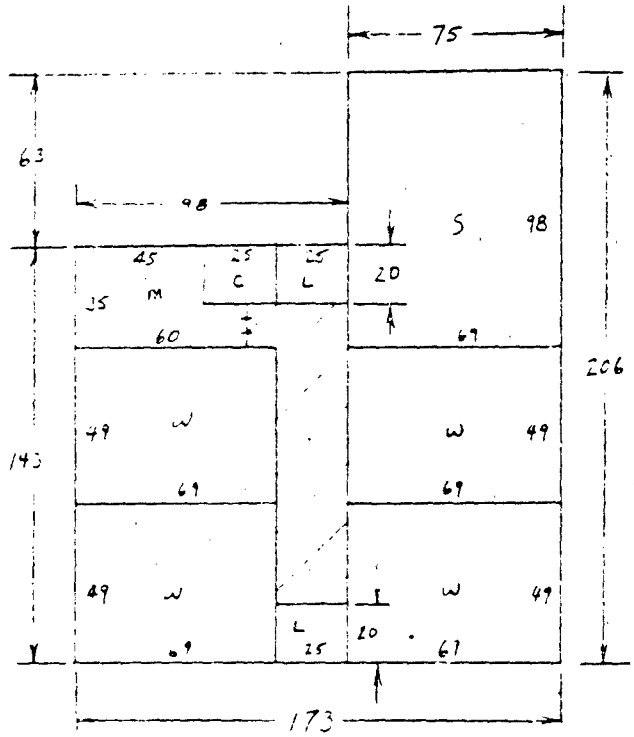
C = 504 ft²
L = 600 ft²/ea
S = 3195 ft²/ea
M = 2016 ft²
W = 3381 ft²/ea
* Total Area = 38,308
* Exterior Wall = 12030 (15' Wall)
Internal Wall = 10030 (15' Wall)
Blast Door No. = 6

Design No. 2-B
Random 212

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ____ 19 ____ CHECKED BY: mot DATE CHECKED: ____ 19 ____



W = 3381 ft²/ea.

S = 6762 ft²

M = 1800 ft²

L = 500 ft²/ea

C = 500 ft²

Total Area = 29,500 ft² 1-25

Pit Bay

Exterior Wall = 11,370 ft²

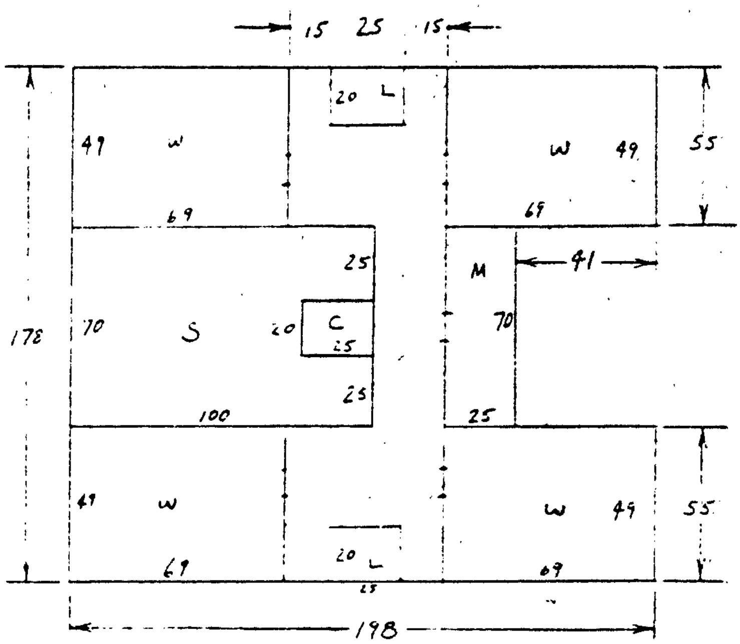
Interior Wall = 7305 ft²

Design 2-9

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ____ 19 ____ CHECKED BY: mwt DATE CHECKED: ____ 19 ____



W = 3381 ft²/ea
S = 6500 ft² Total
M = 1750 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area = 32,400 ft²
Exterior Wall = 12510 ft²
Interior Wall = 6810 ft²
Pit Bay

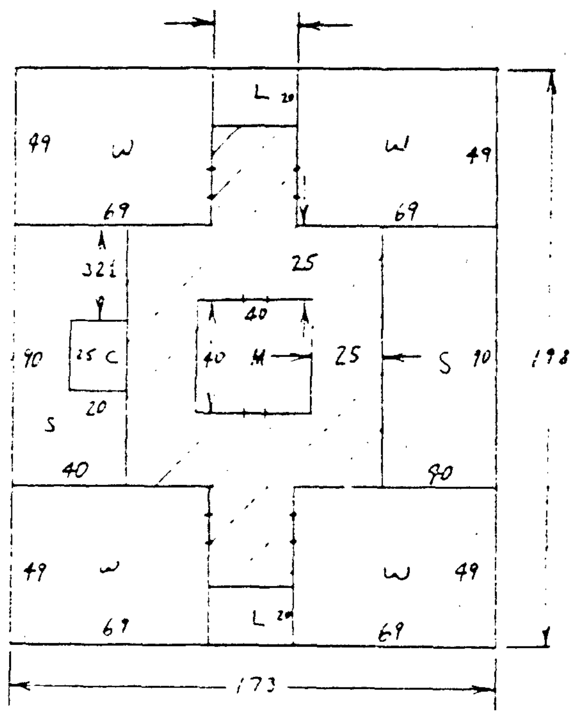
Blast Door No = 5

Design 2-10

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MWV DATE: ____ 19 ____ CHECKED BY: mwb DATE CHECKED: ____ 19 ____



W = 3381 ft²/ea
S = 6700 ft²
M = 1600 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area = 34 300 ft²
External Wall = 11,130 ft²
Internal Wall = 9480 ft²
Blast Door No = 6
PIT BAY

DESIGN 2-11

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: mwb DATE: ____ 19 ____ CHECKED BY: MW DATE CHECKED: ____ 19 ____

	2-1		2-2		2-3		2-4	
1 • Total Floor Area (H)	7	21	5	15	1	3	8	24
2 • Oper. Efficiency 2a - Bay - Main - Bay (L)	10	10	7	7	10	10	6	6
2b - Loadout (H) Forklift - 10, Cranes - 7	10	30	10	30	10	30	10	30
3 • Expandability (L)	10	10	10	10	10	10	10	10
4 • Load Dock Separation (H)	10	30	10	30	10	30	10	30
5 • Perimeter Wall Area/Vol. (M)	9	18	9	18	8	16	9	18
6 • Bay Interior Wall Area/Vol. (M)	4	8	5	10	4	8	7	14
7 • "Squareness" of S.M.L.&C. (M)	2	4	10	20	10	20	8	16
8 • Quantity of Blast Doors (L) 5 Doors = 10 ; 6 Doors = 9	9	9	10	10	9	9	10	10
9 • Weighing Bay Location (L) (Int/Ext) Ext = 8, Int = 10	9	9	8	8	8	8	8	8
10 • Quantity of Maint. Bays (H) 1 Bay = 10, 2 Bays = 5	10	30	10	30	10	30	10	30
11 • Equipment Needs (H) - Base Needs 2 Forklift = 10	10	30	10	30	10	30	10	30
- Preliminary Fork = 10 ; Cr = 5	10	30	10	30	10	30	10	30
- Pack Fronts Fork = 10 ; Cr = 5	10	30	10	30	10	30	10	30
		269		278		261		236

Multipliers:
H = 3
M = 2
L = 1

Ceiling Ht.
Ave Wall = 10'
Pac-Man = 15'
Pits = 16'

Floor Area Ranking:	
30 - 32.5K	= 10
32.5 - 35	= 9
35 - 37.5	= 8
37.5 - 40	= 7
40 - 42.5	= 6
42.5 - 45.	= 5
45 - 47.5	= 4
47.5 - 50	= 3
50 - 52.5	= 2
52.5 - 55	= 1
55 → ∞	= 0

Exterior Area		Int. Area
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: ____ DATE: ____ 19 ____ CHECKED BY: ____ DATE CHECKED: ____ 19 ____

		2-5		2-6		2-7		2-8	
1	Total Floor Area (H)	5	15	7	21	7	21	8	24
2	Oper. Efficiency								
2a	- Bay - Main - Bay (L)	10	10	6	6	10	10	10	10
2b	- Loadout (H)	10	30	10	30	7	21	7	21
3	Expandability (L)	10	10	10	10	10	10	10	10
4	Load Dock Separation (H)	10	30	10	30	10	30	10	30
5	Perimeter Wall Area/Vol. (M)	8	16	9	18	2	4	4	8
6	Bay Interior Wall Area/Vol. (M)	9	18	0	0	0	0	0	0
7	"Squareness" of S.M.L &C (M)	10	20	9	18	5	10	10	20
8	Quantity of Blast Doors (L) — 5 Doors = 10; 6 Doors = 9	9	9	10	10	9	9	9	9
9	Weapons Bay Location (L) (Int-Ext) — Ext = 8; Int = 10	8	8	8	8	8	8	8	8
10	Quantity of Maint. Bays (H) — 1 Bay = 10, 2 Bays = 5	10	30	10	30	10	30	10	30
11	Equipment Needs (H)								
	- Base Needs — 2 Floors = 10; 3 Floors = 7	10	30	10	30	7	21	7	21
	- Pitmanship — Fall 10 ; Ceil 0	10	30	10	30	0	0	0	0
	- Pac Pests — Fall 10 ; Ceil 7	10	30	10	30	7	21	7	21
			236		271		195		212

MULTIPLIERS:
H = 3
M = 2
L = 1

CEILING HT.
Ave Wall = 10'
PAC-MAN = 15'
Pits = 15'

FLOOR AREA RANKING:		EXTERIOR AREA		INT. AREA
30 - 32.5K	= 10	8160 - 8680	= 10	5000 - 5500
32.5 - 35	= 9	8680 - 9200	= 9	5500 - 6000
35 - 37.5	= 8	9200 - 9732	= 8	6000 - 6500
37.5 - 40	= 7	9732 - 10260	= 7	6500 - 7000
40 - 42.5	= 6	10260 - 10780	= 6	7000 - 7500
42.5 - 45	= 5	10780 - 11304	= 5	7500 - 8000
45 - 47.5	= 4	11304 - 11828	= 4	8000 - 8500
47.5 - 50	= 3	11828 - 12352	= 3	8500 - 9000
50 - 52.5	= 2	12352 - 12900	= 2	9000 - 9500
52.5 - 55	= 1	12900 - 13400	= 1	9500 - 10000
55 → ∞	= 0	13400 →	= 0	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MWB DATE: ____ 19 ____ CHECKED BY: MW DATE CHECKED: ____ 19 ____

		2-9			2-10			2-11			
1	Total Floor Area (H)	10	30		9	27		9	27		
2, 2a	Oper. Effiency - Bay-Main-Bay (L)	5	5		6	6		10	10		
2b	- Loadout (H)	7	21		7	21		7	21		
3	Expandability (L)	10	10		10	10		10	10		
4	Load Dock Separation (H)	10	30		10	30		10	30		
5	Perimeter Wall Area/Vol. (M)	4	8		2	4		5	10		
6	Bay Interior Wall Area/Vol. (M)	6	12		7	14		3	6		
7	"Squareness" of S.M.L. & C (M)	10	20		8	16		10	20		
8	5 Doors = 10 ; 6 Doors = 9 Quantity of Blast Doors (L)	10	10		10	10		9	9		
9	Ext = 8 ; Int = 10 Weapons Bay Location (L) (Int/Ext)	8	8		8	8		8	8		
10	1 Bay = 10, 2 Bays = 5 Quantity of Maint. Bays (H)	10	30		10	30		10	30		
11	Equipment Needs (H)										
	- Base Needs 2 Fuel = 10, 1 Fuel = 7	7	21		7	21		7	21		
	- Pr... Fuel = 10 : C = 0	0	0		0	0		0	0		
	- Px Proto Fuel = 10 : C = 5	7	21		7	21		7	21		
			226			218			223		

MULTIPLIERS:
H = 3
M = 2
L = 1

CEILING HT.
Ave Wall = 10'
PAC-MAN = 15'
Pits = 15'

FLOOR AREA RANKING:

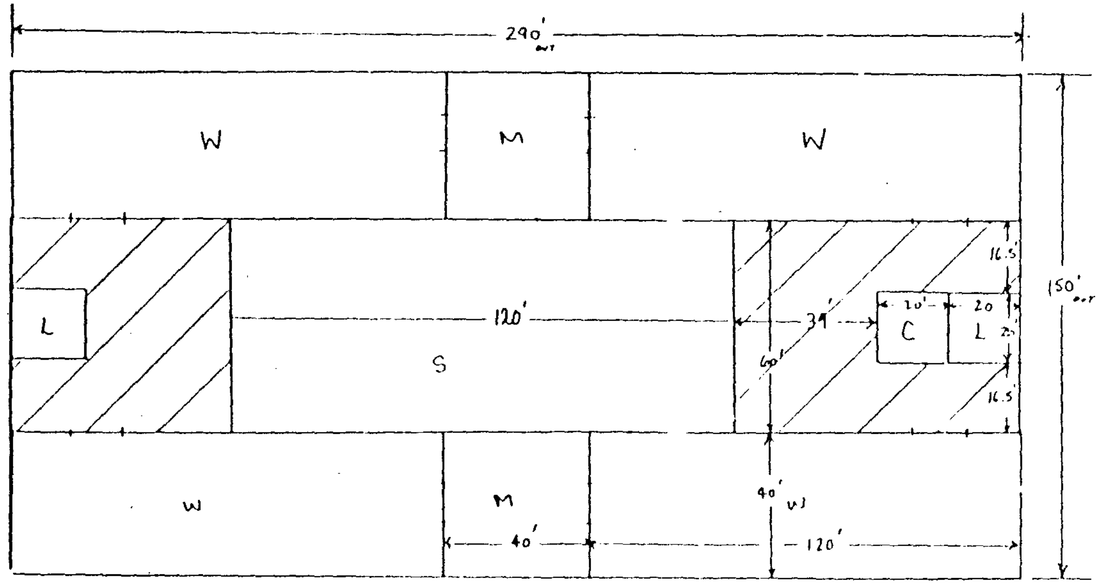
30 - 32.5K = 10
32.5 - 35 = 9
35 - 37.5 = 8
37.5 - 40 = 7
40 - 42.5 = 6
42.5 - 45. = 5
45 - 47.5 = 4
47.5 - 50 = 3
50 - 52.5 = 2
52.5 - 55 = 1
55 → ∞ = 0

EXTERIOR AREA		INT. AREA
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT LAYOUT
BY LMY DATE ____ 19 ____ CHECKED BY mwb DATE CHECKED ____ 19 ____



Square Footages

W = 4800 ea (2)	Access Area = 8220 ft²
S = 8400	Total Area = 43500 ft²
M = 1600 ea (2)	Exterior Wall = 8800 ft²
L = 500 ea (2)	Interior Wall = 7200 ft²
C = 500	Blast Door No = 8

120 x 90 BAY

Design 3-1

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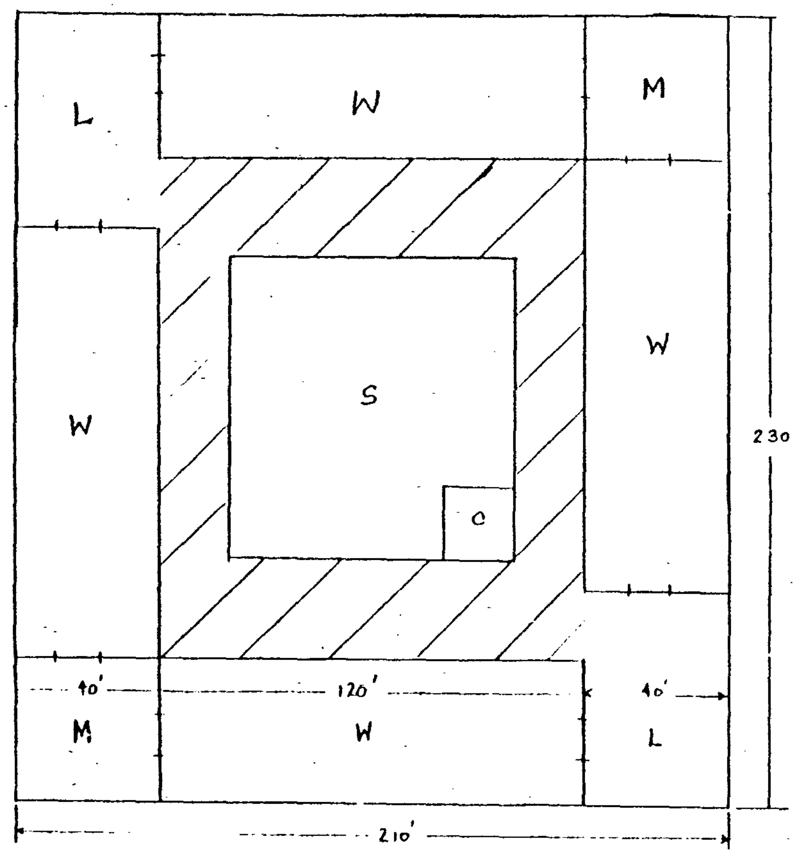
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7012 SPONSOR: CERL
SUBJECT: LAYOUT
BY: LMV DATE: ______ 19__ CHECKED BY: nwf DATE CHECKED: ______ 19__



Square Footage

W = 4800 ea (4)
S = 6000
M = 1600 ea (2)
L = 2400 ea (2)
C = 400
Access = 8000 ft²
Total Area = 48 500 ft² o/r
Exterior Wall = 8800 ft
Interior Wall = 8000 ft
Blast Door = 8
120 × 40 BAY

Design 3-2

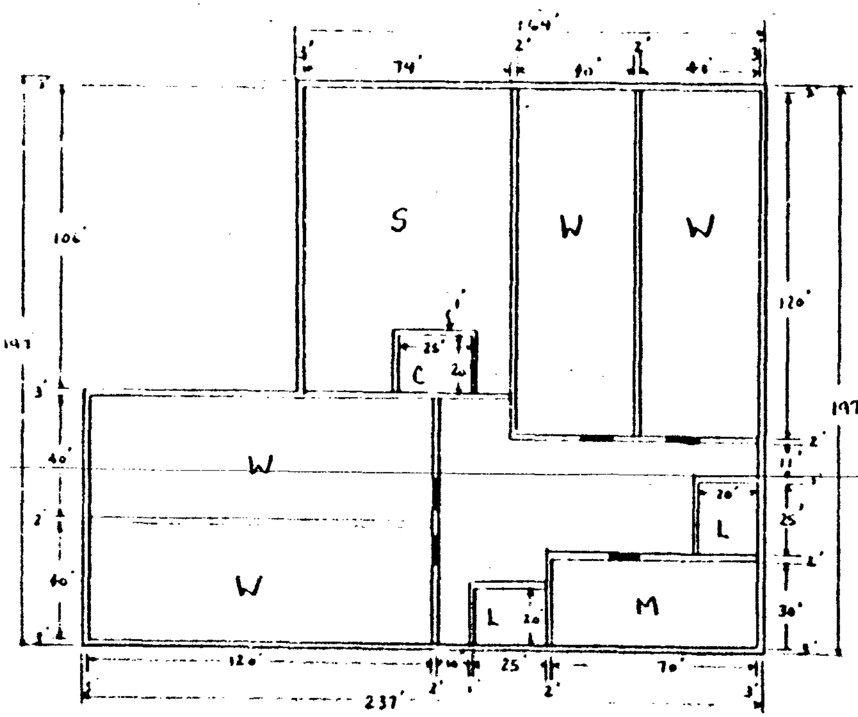
SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible] DATE ____ 19 ____ CHECKED BY: [illegible] DATE CHECKED ____ 19 ____

		3-1		3-2	
1 •	Total Floor Area (H)	5	15	3	15
2 •	Oper. Effiency				
2a	- Bay-Main-Bay (H)	10	10	10	10
2b	- Loadout (H)	10	30	10	30
3 •	Expandability (L)	10	10	10	10
4 •	Load Dock Separation (H)	10	30	10	30
5 •	Perimeter Wall Area/Vol (M)	9	18	9	18
6 •	Bay Interior Wall Area/Vol. (M)	10	20	[illegible]	20
7 •	Squareness of B.M. [illegible] (M)	[illegible]	20	[illegible]	20
8 •	5 Doors = 10 ; 6 Doors = 9 (L) Quantity of Blast Doors	5	5	5	5
9 •	Ext = 8 , Int = 10 Weapons Bay Location (L) (Ext/Int)	8	8	8	8
10 •	1 Bay = 10, 2 Bays = 5 Quantity of Maint Bays (H)	5	15	5	15
11 •	Equipment Needs (H)				
	- Base Needs 2 Fixed = 10 [illegible] = 7	10	30	10	30
	- [illegible] Fix = 10 . Cart [illegible]	[illegible]	30	[illegible]	30
	- Fix Press Fix = 10 Cart 7	10	30	10	30
			271		271

Multipliers:	Floor Area Ranking:	Exterior Area	Int Area
H = 3	30 - 32.5 = 10	8160 - 8680 = 10 =	5000 - 5500
M = 2	32.5 - 35 = 9	8680 - 9200 = 9 =	5500 - 6000
L = 1	35 - 37.5 = 8	9200 - 9732 = 8 =	6000 - 6500
	37.5 - 40 = 7	9732 - 10260 = 7 =	6500 - 7000
	40 - 42.5 = 6	10260 - 10780 = 6 =	7000 - 7500
Ceiling Ht.	42.5 - 45 = 5	10780 - 11304 = 5	7500 - 8000
Ave Wall = 10'	45 - 47.5 = 4	11304 - 11828 = 4 =	8000 - 8500
Pac-Man = 15'	47.5 - 50 = 3	11828 - 12352 = 3 =	8500 - 9000
Pits = 16'	50 - 52.5 = 2	12352 - 12900 = 2 =	9000 - 9500
	52.5 - 55 = 1	12900 - 13400 = 1 =	9500 - 10000
	55 → ∞ = 0	13400 → = 0 =	10000 →



C = 500 ft²
L = 500 ft²/ea
S = 7844 ft²
M = 2100 ft²
W = 4800 ft²

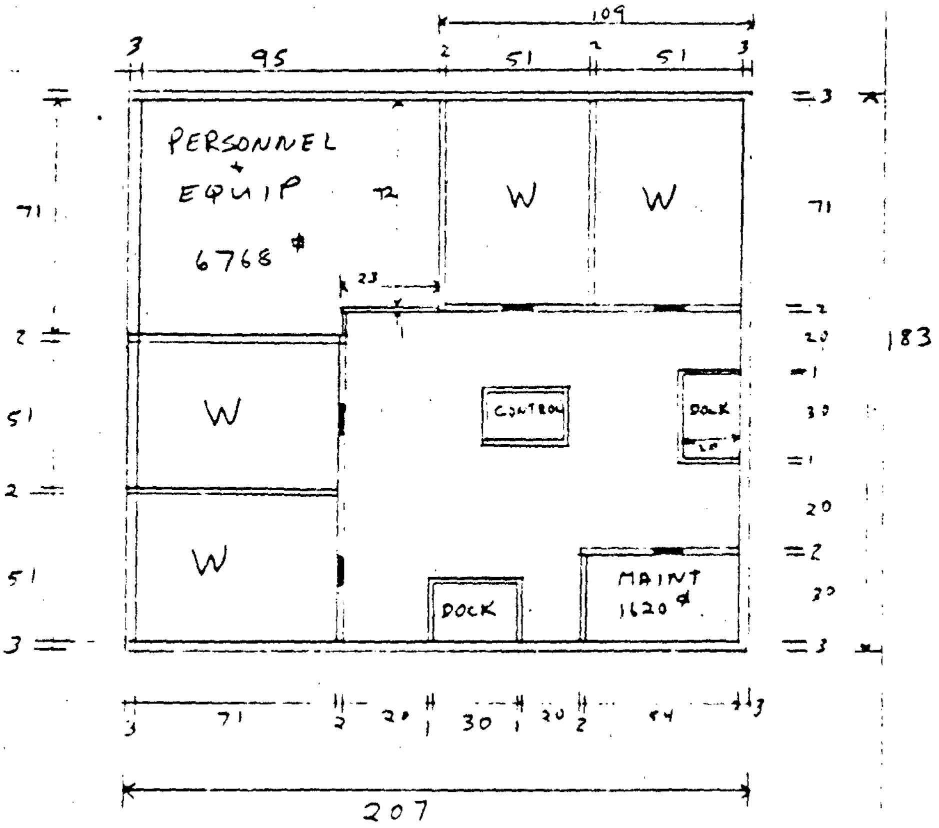
Total Area = 38732 ft²
Exterior Wall = 8630 ft²
Interior Wall = 6700 ft²
No. Blast Doors = 5
120 x 40 BAY

Design No 4-1
Ranking 296

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT LAYOUT - 51 x 71 INTERIOR BAY
BY ____ DATE ____ 19 ____ CHECKED BY ____ DATE CHECKED ____ 19 ____



W: 3621 ft²
S = 6768 ft²
M = 1620 ft²
L: 600 ft²/ea
C = 600 ft²
Total Area = 37,881 ft²
Exterior Wall = 11,700 ft² (15' Tall)
Interior Wall = 8580 ft²
Blast Door No: 5

1-35

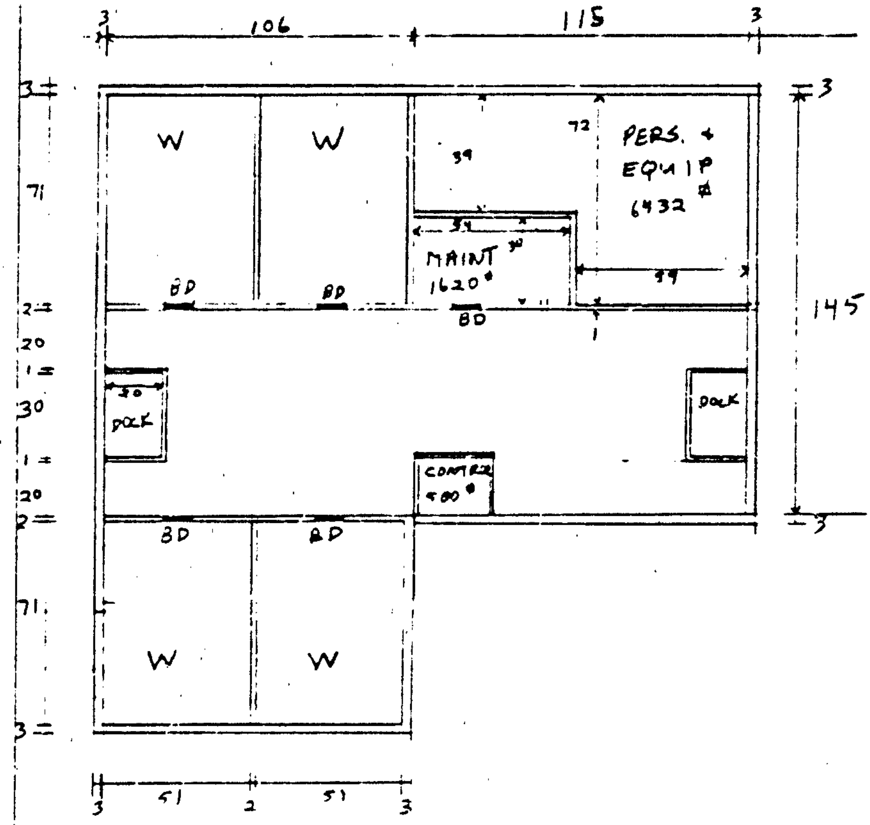
Design 4-2

DIVIDING WALL BAY

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT - 51' x 31' INTERIOR BAYS
BY: R. MORRIS DATE: 13 JUL 1982 CHECKED BY: mob DATE CHECKED: ____ 19 ____



W = 1581 ft²
S = 6432 ft²
M: 1620 ft²
L = 600 ft²/ea
C = 500 ft²
Total Area = 42,307
Exterior Wall = 13,340 ft² (15' Tall)
Interior Wall = 7515 ft²
Blast Door No. = 5
DIVIDING WALL BAY

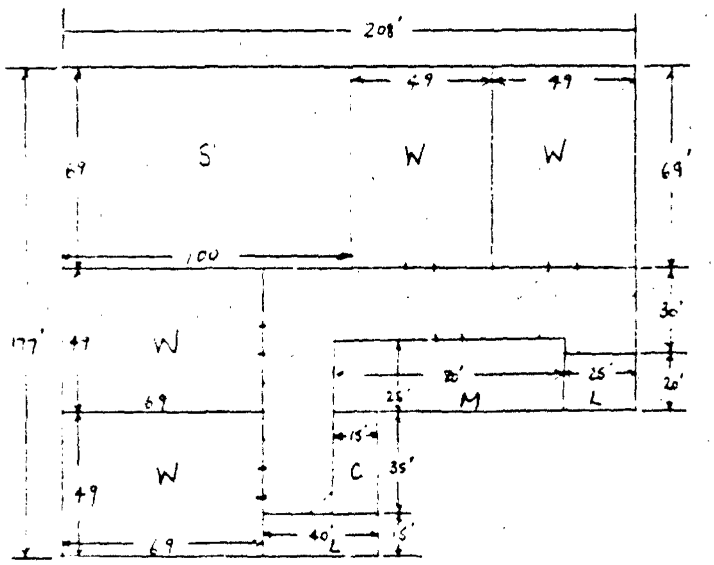
1-36

DESIGN 4-3

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE. ____ 19 ____ CHECKED BY. mwb DATE CHECKED: ____ 19 ____



W: 3381 ft²/ea
S = 6900 ft²
M = 2000 ft²
L = 500 ft²/ea
C = 525 ft²
Total Area = 31 800 ft²
Exterior Wall = 11,550 ft²
Interior Wall = 9105 ft
Blast Door No. = 5

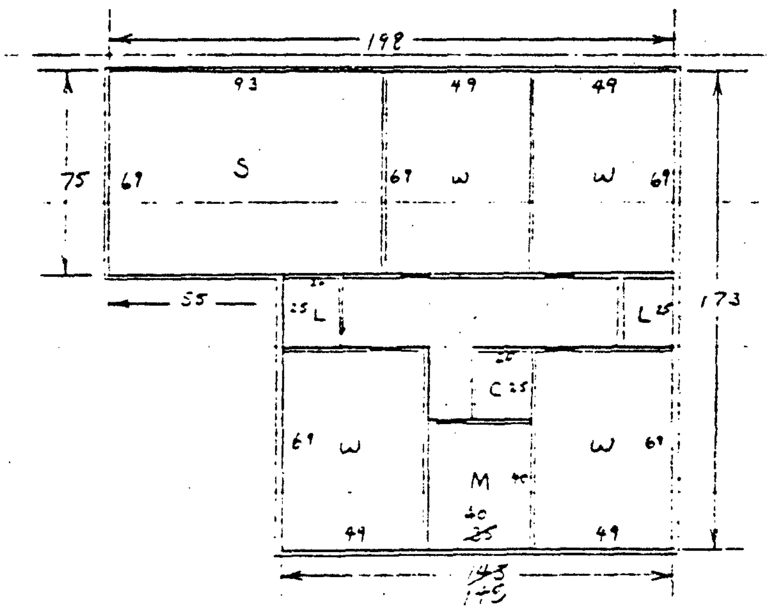
PIT BAY 1-37

DESIGN 4-4

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: N.W. DATE: ____ 19 ____ CHECKED BY: nwb DATE CHECKED: ____ 19 ____



Above Ground

W = 3381 ft²/ea (F.T Bays)
S = 6417 ft²
M: 1400 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area = 28 864 ft²
Exterior Wall = 11,130 ft²
Interior Wall = 7605 ft²
Blast Door No = 5

Design 4-5

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible] DATE: ____ 19 ____ CHECKED BY: MW DATE CHECKED: ____ 19 ____

		6-1		6-2		6-3		6-4		6-5	
1	Total Floor Area (H)	8	24	7	21	6	18	10	30	10	30
2	Oper. Effiency										
2a	- Bay-Main-Bay (L)	10	10	5	5	10	10	5	5	10	10
2b	- Loadout (H)	10	30	7	21	7	21	7	21	7	21
3	Expandability (L)	10	10	10	10	10	10	10	10	10	10
4	Load Dock Separation (H)	10	30	10	30	10	30	10	30	10	30
5	Perimeter Wall Area/Vol. (M)	10	20	4	8	1	2	4	8	5	10
6	Bay Interior Wall Area/Vol. (M)	7	14	3	6	5	10	2	4	5	10
7	"Squareness" of S.M.L.C. (M)	10	20	10	20	10	20	7	14	10	20
8	5 Doors = 10; 6 Doors = 9 Quantity of Blast Doors (L)	10	10	10	10	10	10	10	10	10	10
9	Ext = 8; Int = 10 Weighing Bay Location (L) (Ext-Int)	8	8	8	8	8	8	8	8	8	8
10	1 Bay = 10, 2 Bays = 5 Quantity of Maint. Bays (H)	10	30	10	30	10	30	10	30	10	30
11	Equipment Needs (H) - Gate Needs 2 Tools = 10, 3 Tools = 7	10	30	7	21	7	21	7	21	7	21
	- Perimeter Fence [illegible]	10	30	0	0	0	0	0	0	0	0
	- Pit Feats [illegible]	10	30	7	21	7	21	7	21	7	21
			296		211		211		212		231

Multipliers:
H = 3
M = 2
L = 1

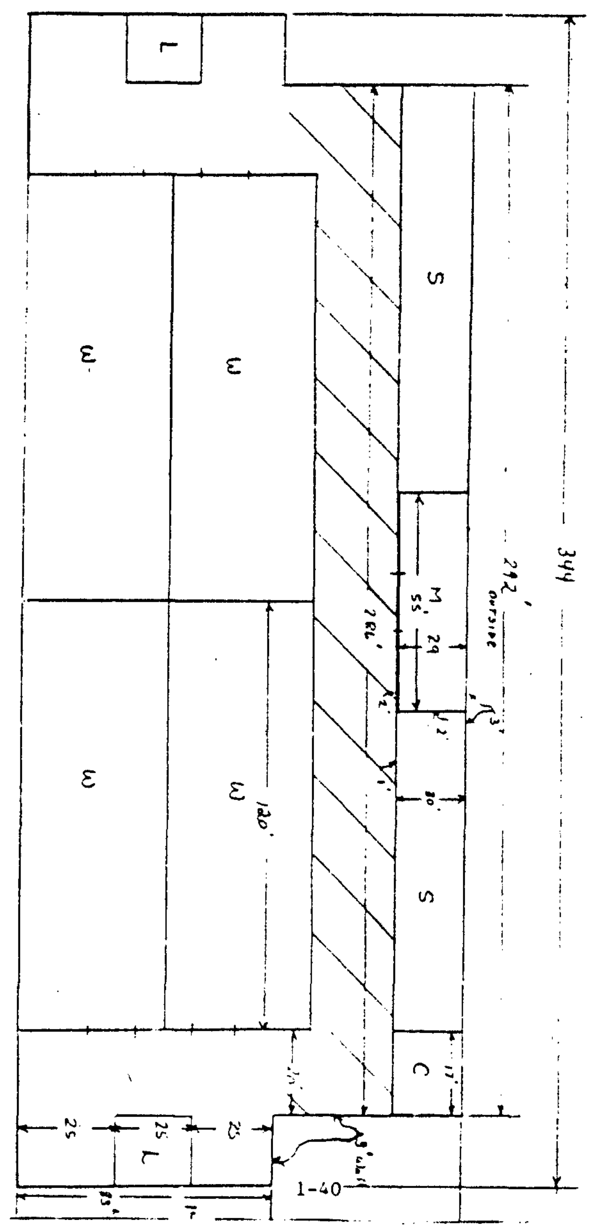
Ceiling Ht.
Ave Wall = 10'
Pac-Man = 15'
Pits = 15'

Floor Area Ranking:		Exterior Area		Int. Area
30 - 32.5	= 10	8160 - 8680	= 10	5000 - 5500
32.5 - 35	= 9	8680 - 9200	= 9	5500 - 6000
35 - 37.5	= 8	9200 - 9732	= 8	6000 - 6500
37.5 - 40	= 7	9732 - 10260	= 7	6500 - 7000
40 - 42.5	= 6	10260 - 10780	= 6	7000 - 7500
42.5 - 45	= 5	10780 - 11304	= 5	7500 - 8000
45 - 47.5	= 4	11304 - 11828	= 4	8000 - 8500
47.5 - 50	= 3	11828 - 12352	= 3	8500 - 9000
50 - 52.5	= 2	12352 - 12900	= 2	9000 - 9500
52.5 - 55	= 1	12900 - 13400	= 1	9500 - 10000
55 → ∞	= 0	13400 →	= 0	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT LAYOUT
BY MV DATE ____ 19 ____ CHECKED BY nwb DATE CHECKED ____ 19 ____



W = 4800 ft²/ea
S = 6270 ft²
M = 1595 ft²
L = 500 ft²/ea
C = 510 ft²

Total Area = 45488 ft²
Exterior Area = 9700 ft²
Interior Area = 8330 ft²
Blast Door = 5

120X40 BAY

Design 5-1

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

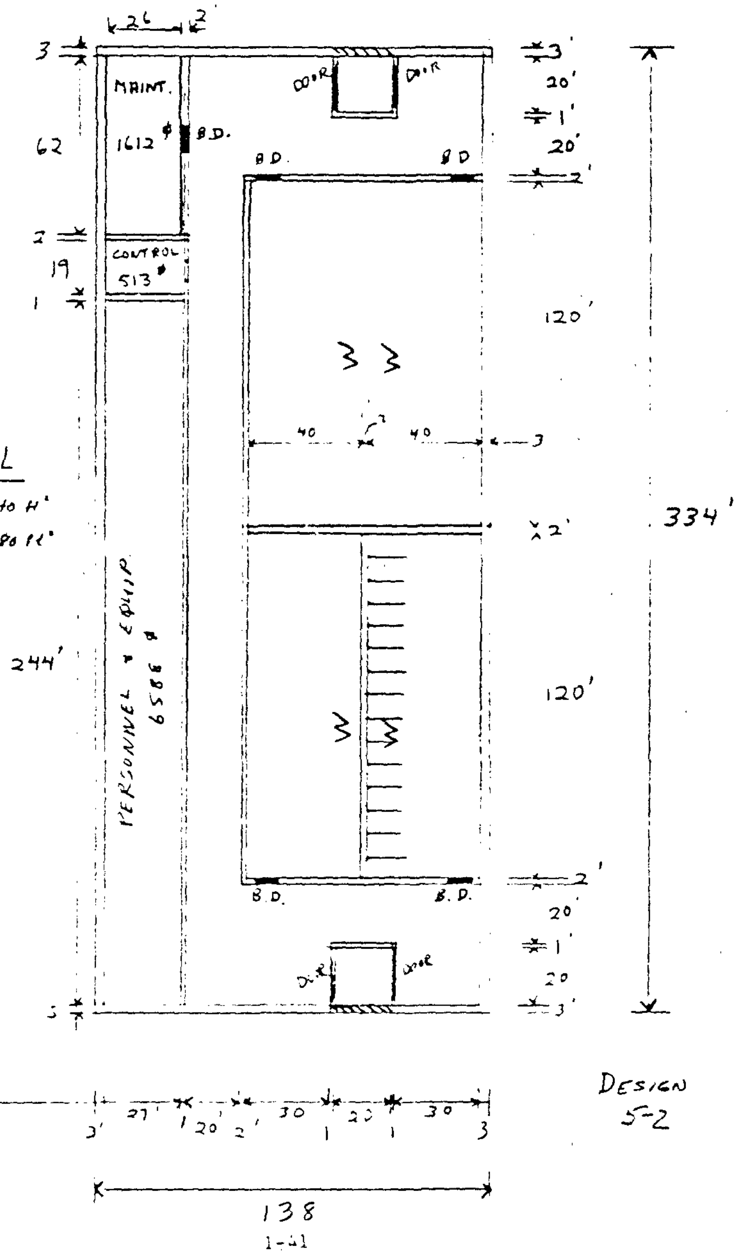
SHEET NO. 1 OF 1

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT LAYOUT
BY E. MORRIS DATE 7 JUL 19 82 CHECKED BY nwb DATE CHECKED. ______ 19 __

W: 4800 ft²
S = 6588 ft²
M = 1612 ft²
L: 500 ft²/ea
C = 513 ft²
46,092 ¢ TOTAL

Exterior Wall = 9440 ft²
Interior Wall = 8080 ft²
Blast Doors = 5

120x40 BAY



DESIGN 5-2

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

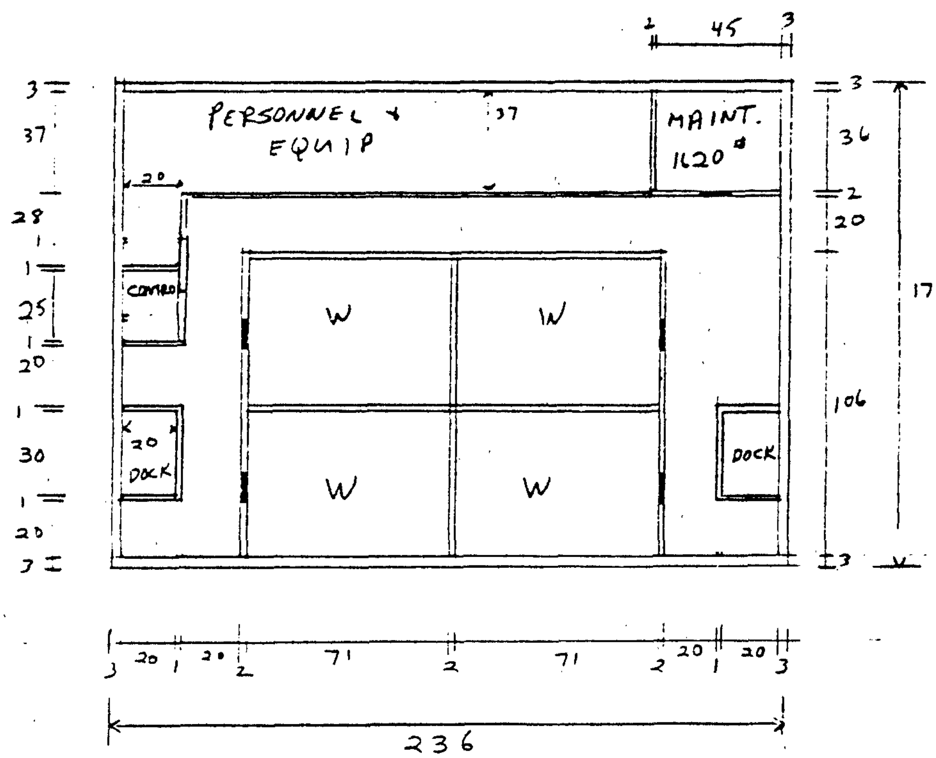
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT - 51' X 71' INTERIOR BAY
BY: B. MORRIS DATE: 13 JUL 19 82 CHECKED BY: mwb DATE CHECKED: ____ 19 ____

interior wall - 671 x 15 = 10,065

exterior wall - 812 ft length x 15' ht = 12,180

5 B.D

40 120'



W: 3621 ft²/ea
S: 7231 ft²
M: 1620 ft²
L: 600 ft²/ea
C: 500 ft²

TOTAL AREA = 40120 ft²
EXTERIOR AREA = 12180 ft²
INTERIOR AREA = 10065 ft²
BLAST DOOR NO = 5
DIVIDING WALL BAY

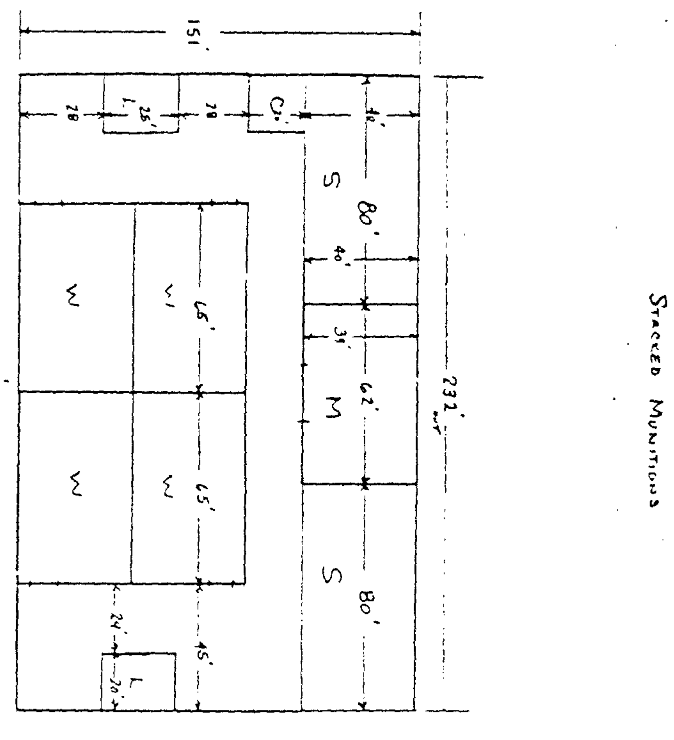
DESIGN 5-3

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: LMV DATE: ____ 19 ____ CHECKED BY: mwb DATE CHECKED: ____ 19 ____

W = 2600 ft²/ea
S = 6400 ft²
M = 2418 ft²
L = 500 ft²/ea
C = 400 ft²



226 internal

Total Area: 35032 ft²
Exterior Area = 13794 ft²
Interior Area 10819 ft²
Blast Doors = 6

DESIGN
S-4

Pit Bay

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible] DATE: ____ 19 ____ CHECKED BY: [illegible] DATE CHECKED: ____ 19 ____

		5-1		5-2		5-3		5-4	
1	Total Floor Area (H)	3	9	4	12	6	18	8	24
2 / 2a	Oper. Effiency - Bay - Main - Bay (L)	2	2	1	1	2	2	3	3
2b	- Loadout (H)	10	30	10	30	7	21	7	21
3	Expandability (L)	10	10	10	10	10	10	10	10
4	Load Dock Separation (H)	10	30	10	30	10	30	10	30
5	Perimeter Wall Area/Vol. (M)	8	16	8	16	3	6	0	0
6	Bay Interior Wall Area/Vol. (M)	4	8	4	8	0	0	0	0
7	"Squareness" of S M L &C (M)	0	0	0	0	2	4	10	20
8	5 Doors = 10; 6 Doors = 9 Quantity of Blast Doors (L)	10	10	10	10	10	10	10	10
9	Ext = 8; Int = 10 Weapons Bay Location (L) (Int/Ext)	8	8	8	8	8	8	8	8
10	1 Bay = 10, 2 Bays = 5 Quantity of Maint. Bays (H)	10	30	10	30	10	30	10	30
11	Equipment Needs (H)								
	- Base Needs 2 Fixed = 10, Relocate = 7	10	30	10	30	7	21	7	21
	- Permanency Fixed = 10; Cert = 0	10	30	10	30	0	0	0	0
	- Pipe Rcts Fix = 10; Cert = 7	10	30	10	30	7	21	7	21
			243		245		181		198

MULTIPLIERS:
H = 3
M = 2
L = 1

CEILING HT.
Ave Wall = 10'
PAC-MAN = 15'
PITS = 15'

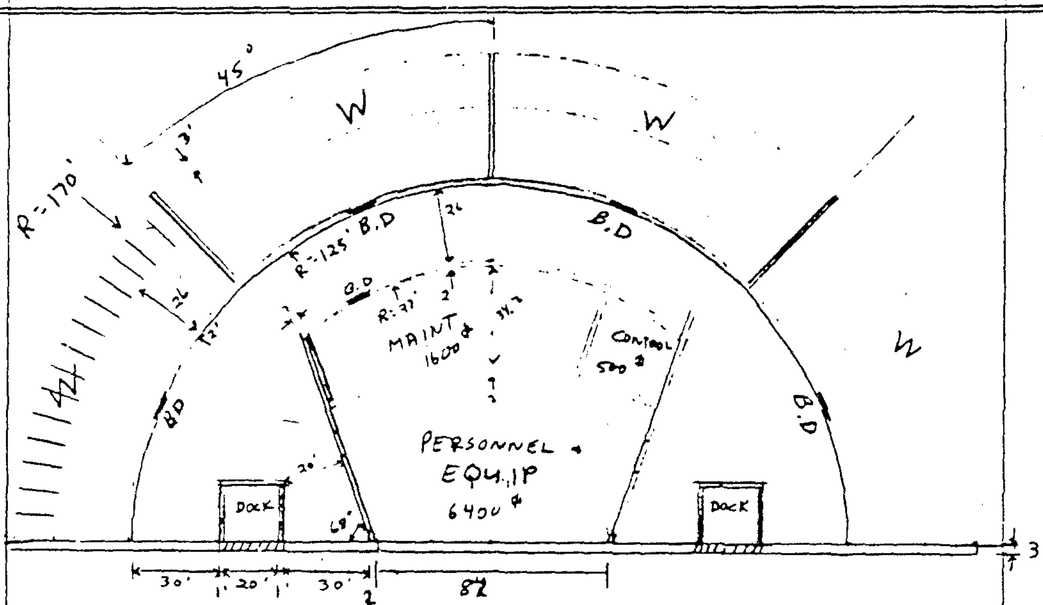
FLOOR AREA RANKING:
30 - 32.5K = 10
32.5 - 35 = 9
35 - 37.5 = 8
37.5 - 40 = 7
40 - 42.5 = 6
42.5 - 45 = 5
45 - 47.5 = 4
47.5 - 50 = 3
50 - 52.5 = 2
52.5 - 55 = 1
55 → ∞ = 0

Exterior Area		Int. Area
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. 1 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CIRCULAR LAYOUT
BY: E. MORRIS DATE 7 JUL 19 82 CHECKED BY: [signature] DATE CHECKED: ______ 19 ___



W = 4600 ft²/ea (avg)
S = 6400 ft²
M = 1600 ft²
L = 400 ft²/ea
C = 500 ft²
TOTAL AREA = 46,416 ft²
EXTERIOR WALL = 8740 ft²
INTERIOR WALL = 4980 ft²
BLAST DOOR NO = 5

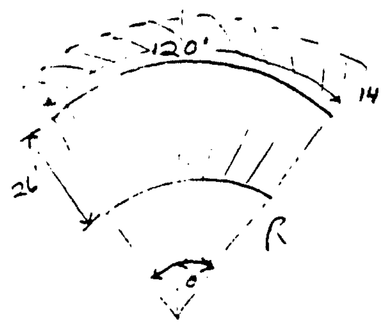
120 X 80 BAY

DESIGN 6-1

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. 2 OF 2

PROJECT NO. 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT (CIRCULAR)
BY R. MORRIS DATE 7 July 19 82 CHECKED BY mwb DATE CHECKED: ____ 19 ____



Arc Length: $2\pi R \frac{\theta}{360°} = 120'$

$R = \frac{120 \times 360}{2\pi\theta}$

$R = 6875.5 \frac{1}{\theta}$

θ	R	∇ area
30	229	13,729
45	153	9,193
60	115	6925
75	92	5540
36	191	11,461
20	344	

Area in 26' section $= \frac{\theta}{360}\left[\pi\left(R^2 - (R-26)^2\right)\right]$

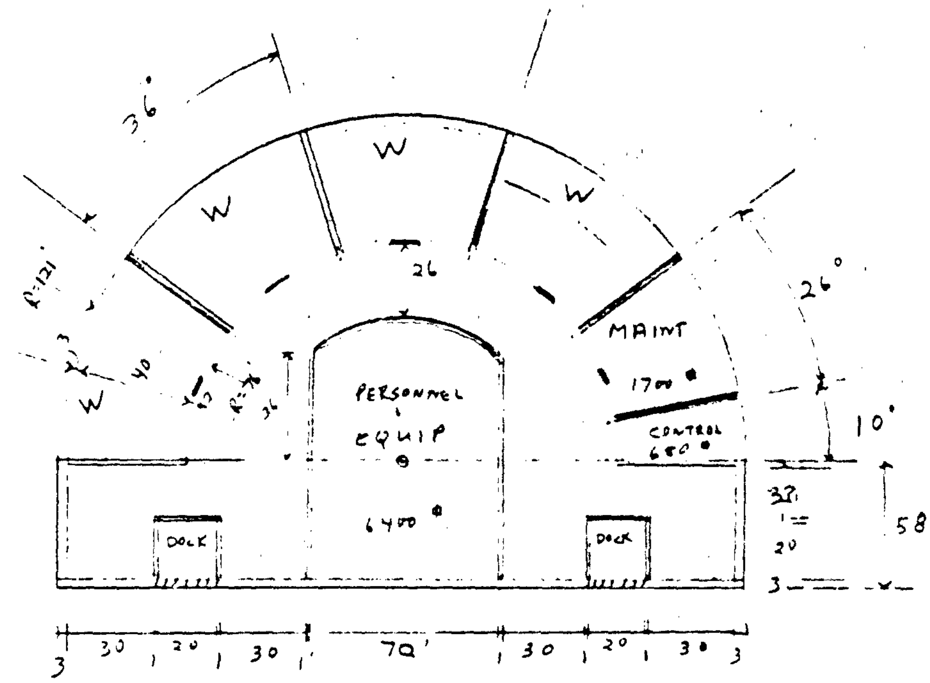
θ	Area (26' section)	+ Area (14')	= Total
30	2941	1730	4671
36	2908	1742	4650
45	2859	1759	4618
60	2777	1789	4566
75	2689	1814	4503

[illegible] $120 \times 40 = 4800$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CIRCULAR LAYOUT - DOUBLE STACKED
BY: B MORRIS DATE: 8 JUL 19 82 CHECKED BY: [signature] DATE CHECKED: 19



W = 2425 ft²/ea (Avg)

S = 6400 ft²

M = 1700 ft²

L = 400 ft²/ea

C = 680 ft²

Total Area = 37,034 ft²

Exterior Wall = 13,284 ft²

Interior Wall = 8370 ft²

Blast Door No = 5

DOUBLE STACKED BAY

DESIGN 6-2

1-47

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

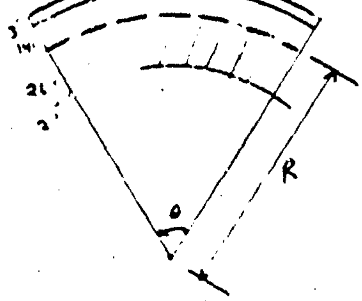
SHEET NO 2 OF 2

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT CIRCULAR LAYOUT - DOUBLE STACKED
BY E. MORRIS DATE 8 JUL 19 82 CHECKED BY [illegible] DATE CHECKED 19

dotted arc length = 7x8 + 9x1 + 2 = 65'

arc length = $2\pi R \frac{\theta}{360} = 65'$

$R = 3724 \frac{1}{\theta}$



θ	R (ft)	shaded area
30°	124	2471
36°	104	2463
45°	83	2419
60°	62	2346

shaded area = $\frac{\theta}{360}\pi\left[(R+14)^2 - (R-26)^2\right]$

for maint area, $\frac{\theta}{360}\pi\left[118^2 - 78^2\right] = 1600 \Rightarrow \theta = 23.3$ (7840)

for control area, $\frac{\theta}{360}\pi\left[118^2 - 78^2\right] = 500 \Rightarrow \theta = \frac{7.3°}{30.6°}$ 32

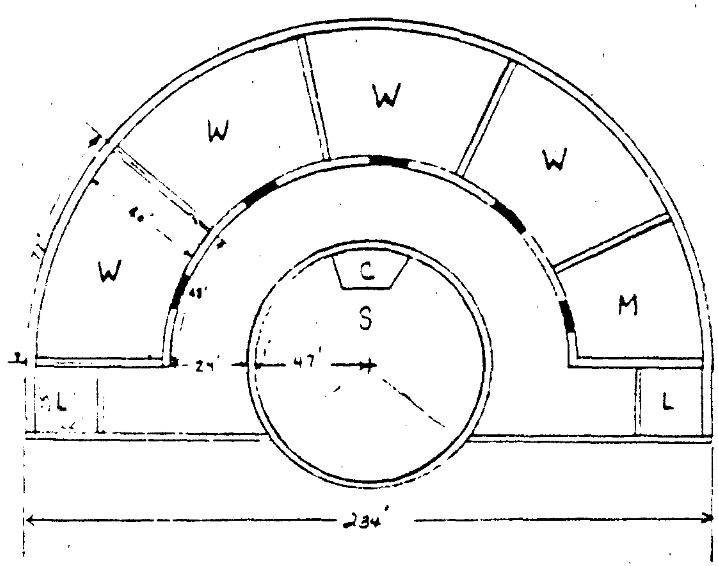
from $R = \frac{3724}{\theta}$, $\theta = \frac{3724}{R}$

R	θ
98	38
100	37.2

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: ____ DATE ____ 19 ____ CHECKED BY ____ DATE CHECKED ____ 19 ____



W = 2425 ft²/ea (avg)

S = 6440 ft²

M = 1700 ft²

L = 500 ft²/ea

C = 500 ft²

Total Area = 27665 ft²

Exterior Wall = 10251 ft²

Interior Wall = 8352 ft²

Blast Door No = 5

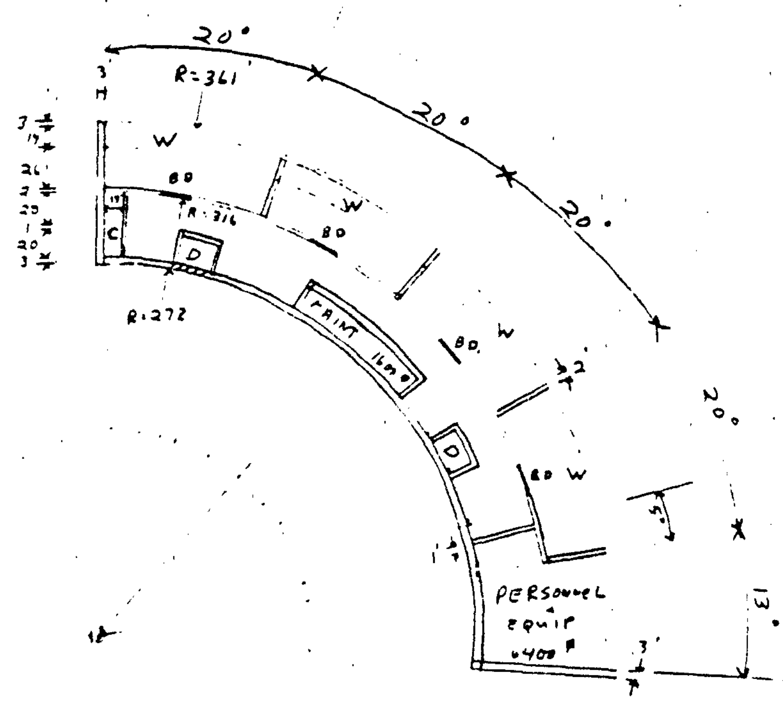
Double Stacked 5x5

Design 6-3

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT CIRCULAR LAYOUT
BY E. MORRIS DATE ____ 19 ____ CHECKED BY nwb DATE CHECKED ____ 19 ____



$$\text{Total area} = \frac{73}{360}\pi(361^2 - 272^2) + 2(3)(89) = 46{,}256\ \text{ft}^2$$

W = 4800 ft²/ea (approx)

S = 6400 ft²

M = 1600 ft²

L = 500 ft²/ea

C = 533 ft²

TOTAL AREA = 46256 ft²

EXTERIOR WALL = 11930 ft²

INTERIOR WALL = [illegible] ft²

BLAST DOOR NO = 5

DOUBLE STACKED BAY

DESIGN 6-4

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ___ OF ___

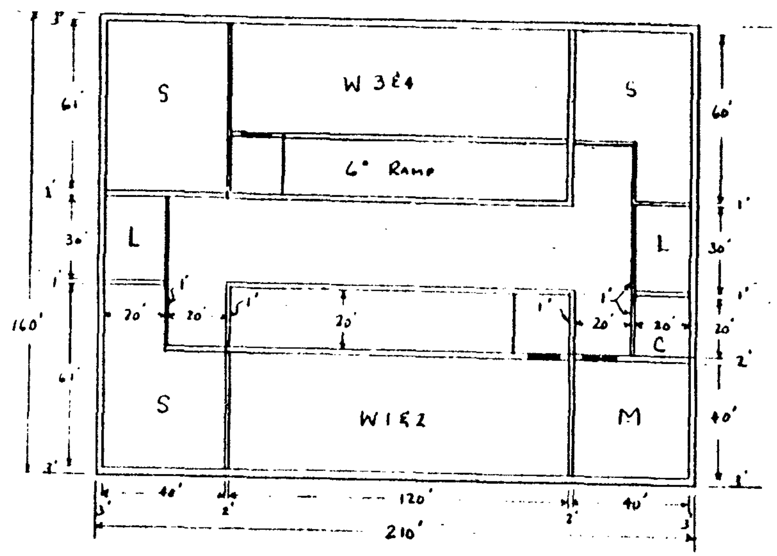
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible] DATE: ___ 19 ___ CHECKED BY: M.W. DATE CHECKED: ___ 19 ___

		6-1		6-2		6-3		6-4	
1	Total Floor Area (H)	4	12	8	24	8	24	4	12
2 / 2a	Oper. Efficency - Bay-Main-Bay (L)	3	3	3	3	3	3	3	3
2b	- Loadout (H)	10	30	7	21	7	21	10	30
3	Expandability (L)	10	10	10	10	5	5	5	5
4	Load Dock Separation (H)	10	30	10	30	10	30	10	30
5	Perimeter Wall Area/Vol (M)	9	18	1	2	5	10	3	6
6	Bay Interior Wall Area/Vol. (M)	10	20	4	8	4	8	6	12
7	"Squareness" of S M, L &C (M)	10	20	10	20	10	20	2	4
8	5 Doors = 10 ; 6 Doors = 9 Quantity of Blast Doors (L)	10	10	10	10	10	10	10	10
9	Ext = 8, Int = 10 Weapons Bay Location (L) (Int/Ext)	8	8	8	8	8	8	8	8
10	1 Bay = 10, 2 Bays = 5 Quantity of Maint. Bays (H)	10	30	10	30	10	30	10	30
11	Equipment Needs (H)								
	- Base Needs [illegible]	10	30	7	21	7	21	10	30
	- [illegible] [illegible]	10	30	0	0	0	0	10	30
	- Px Fronts [illegible] 7	10	30	7	21	7	21	10	30
			281		208		211		240

Multipliers:
H = 3
M = 2
L = 1

Ceiling Ht.
Ave Wall = 10'
Pac-Man = 15'
Pits = 15'

Floor Area Ranking:		Exterior Area		Int Area
30 - 32.5K	= 10	8160 - 8680	= 0	5000 - 5500
32.5 - 35	= 9	8680 - 9200	= 9	5500 - 6000
35 - 37.5	= 8	9200 - 9732	= 8	6000 - 6500
37.5 - 40	= 7	9732 - 10260	= 7	6500 - 7000
40 - 42.5	= 6	10260 - 10780	= 6	7000 - 7500
42.5 - 45	= 5	10780 - 11304	= 5	7500 - 8000
45 - 47.5	= 4	11304 - 11828	= 4	8000 - 8500
47.5 - 50	= 3	11828 - 12352	= 3	8500 - 9000
50 - 52.5	= 2	12352 - 12900	= 2	9000 - 9500
52.5 - 55	= 1	12900 - 13400	= 1	9500 - 10000
55 → ∞	= 0	13400 →	= 0	10000 →



Areas

C = 400 ft²

L = 600 ft²

S = 6440 ft²

M = 1600 ft²

W = 4800 ft²

Total Area = 33,600 ft²

External Wall = 14800 ft²

Internal Wall = 8400 ft²

Blast Door No. = 5

120 x 40 BAYS

Design No. 7-1

Ranked 276

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ___ OF ___

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MWB DATE: ___ 19___ CHECKED BY: XWW DATE CHECKED: ___ 19___

7-1

1 •	Total Floor Area (H)	9	27
2 •	Oper. Efficiency		
2a	– Bay – Maint – Bay (L)	5	5
2b	– Loadout (H) 10 - Forklift, 7 - Crane	10	30
3 •	Expandability (L)	10	10
4 •	Load Dock Separation (H)	10	30
5 •	Perimeter Wall Area/Vol (M)	0	0
6 •	Bay Interior Wall Area/Vol. (M)	4	8
7 •	Squareness of S.M.L. (M)	6	12
8 •	Quantity of Blast Doors (L) 5 Doors = 10; 6 Doors = 9	10	10
9 •	Working Bay Location (L) Ext = 8, Int = 10	8	24
10 •	Quantity of Maint. Bays (H) 1 Bay = 10, 2 Bays = 5	10	30
11 •	Equipment Needs (H)		
	– Base Needs 2 Forklift = 10	10	30
	– Forklift, Crane	10	30
	– Fork, Crane	10	30

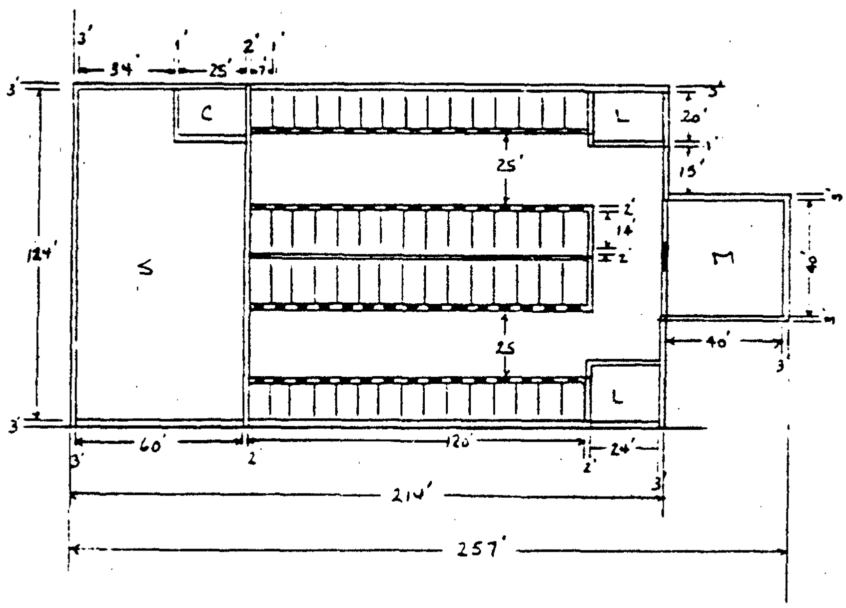
276

Multipliers:	Floor Area Ranking:	Exterior Area		Int. Area
H = 3	30 - 32.5K = 10	8160 - 8680	= 10	5000 - 5500
M = 2	32.5 - 35 = 9	8680 - 9200	= 9	5500 - 6000
L = 1	35 - 37.5 = 8	9200 - 9732	= 8	6000 - 6500
	37.5 - 40 = 7	9732 - 10260	= 7	6500 - 7000
	40 - 42.5 = 6	10260 - 10780	= 6	7000 - 7500
Ceiling Ht.	42.5 - 45. = 5	10780 - 11304	= 5	7500 - 8000
Avg Wall = 10'	45 - 47.5 = 4	11304 - 11828	= 4	8000 - 8500
PAC-MAN = 15'	47.5 - 50 = 3	11828 - 12352	= 3	8500 - 9000
Pits = 16'	50 - 52.5 = 2	12352 - 12900	= 2	9000 - 9500
	52.5 - 55 = 1	12900 - 13400	= 1	9500 - 10000
	55 → ∞ = 0	13400 →	= 0	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Aycu
BY: MXV DATE: ____ 19 ____ CHECKED BY: nwb DATE CHECKED: ____ 19 ____



W = 1920 ft²
S = 6894 ft²
M = 1600 ft²
L = 480 ft²/ea
C = 500 ft²
Total Area = 29798 ft²
Interior Wall = 6780
Exterior Wall = 7620 ft²
Blast Door No = 61

INDIVIDUAL STORAGE BAY

Design No. 9-1

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MWB DATE: ____ 19 ____ CHECKED BY: MW DATE CHECKED: ____ 19 ____

		8-1	
1 •	Total Floor Area (H)	10	30
2 •	Oper. Efficiency		
2a	- Bay - Main - Bay (M)	8	8
2b	- Loadout (H) FL = 10, CR = 7	10	30
3 •	Expandability (L)	5	5
4 •	Load Dock Separation (H) <150' = 0, >150' = 10, opp sides = 10	10	30
5 •	Perimeter Wall Area/Vol (M)	10	20
6 •	Bay Interior Wall Area/Vol (M)	7	14
7 •	"Squareness" of S M I L C (M)	9	18
8 •	Quantity of Blast Doors (L) 5 Doors = 10 ; 6 Doors = 9 etc	0	0
9 •	Weighing Bay Location (L) (In-Ext) Ext = 8, Int = 10	9	9
10 •	Quantity of Maint. Bays (H) 1 Bay = 10, 2 Bays = 5	10	30
11 •	Equipment Needs (H)		
	- Base Needs 2 Fork = 10, 2 Crane = 7	10	30
	- Preliminary Fork = 10, Cr =	10	30
	- Pk Press Fork = 10, Cr = 7	10	30
			284

MULTIPLIERS:

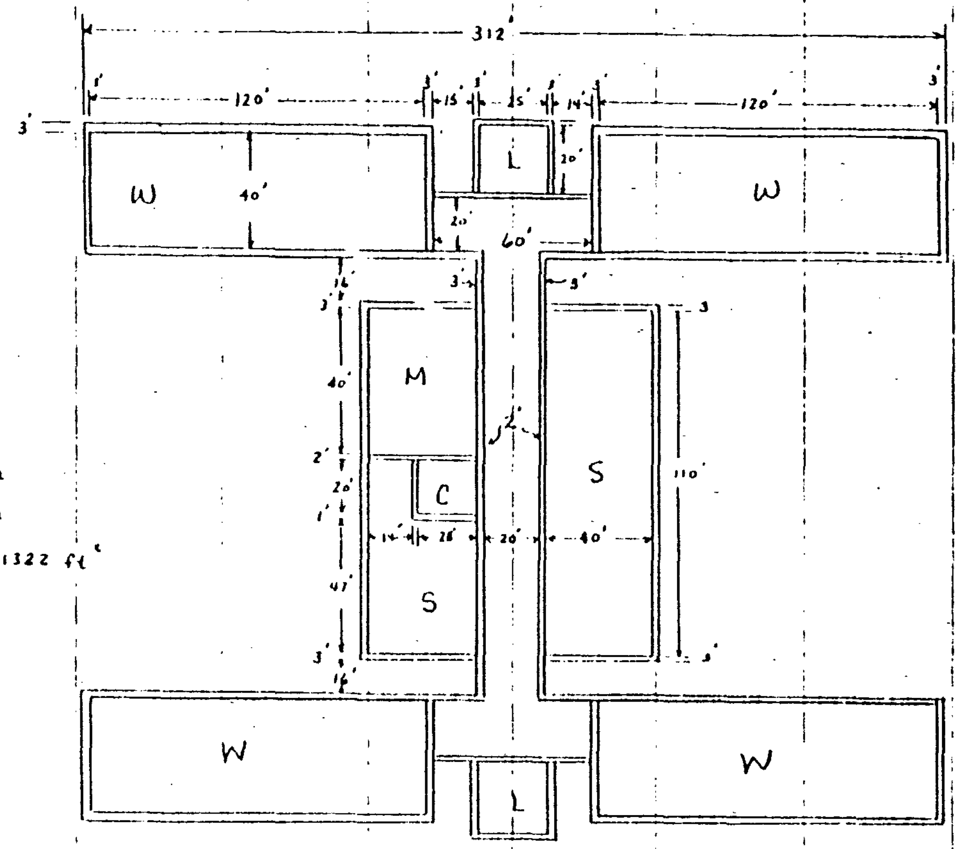
H = 3
M = 2
L = 1

CEILING HT.

Avg Wall = 10'
PAC-MAN = 15'
PITS = 15'

FLOOR AREA RANKING:	
30 - 32.5K	= 10
32.5 - 35	= 9
35 - 37.5	= 8
37.5 - 40	= 7
40 - 42.5	= 6
42.5 - 45	= 5
45 - 47.5	= 4
47.5 - 50	= 3
50 - 52.5	= 2
52.5 - 55	= 1
55 → ∞	= 0

EXTERIOR AREA		INT. AREA
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →



$W = 4800\ ft^2/ea$
$L = 500\ ft^2/ea$
$C = 500\ ft^2$
$S = 6560\ ft^2$
$M = 1600\ ft^2$
TOTAL AREA $= 41322\ ft^2$
120×40 BAY

DESIGN 9-1

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible] DATE: ______ 19 ____ CHECKED BY: MW DATE CHECKED: ______ 19 ____

9-1

1	Total Floor Area (L)	4	12	-6
2	Oper. Effiency			
2a	- Bay - Main - Bay (L)	6	6	
2b	- Loadout (H) FL=10 CR=7	10	30	-
3	Expandability (L)	10	10	
4	Load Dock Separation (H) <150'=0 >150'=10 [illegible] sides=10	0	0	
5	Perimeter Wall Area/Vol. (M)	0	0	
6	Bay Interior Wall Area/Vol. (H)	10	20	
7	"Sequence" of S.M.L. & C (M)	10	20	
8	Quantity of Blast Doors (L) 5 Doors = 10; 6 Doors = 9 etc	10	10	
9	Welding Bay Location (L) (Int/Ext) Ext = 8; Int = 10	8	8	
10	Quantity of Maint. Bays (H) 1 Bay = 10, 2 Bays = 5	10	30	
11	Equipment Needs (H)			
	- Base Needs 2 Fixed = 10 [illegible] = 7	10	30	
	- Performance FL = 10, CR = 7	10	30	
	- [illegible] Prots FL = 10, CR: 7	10	30	

236

Multipliers:
H = 3
M = 2
L = 1

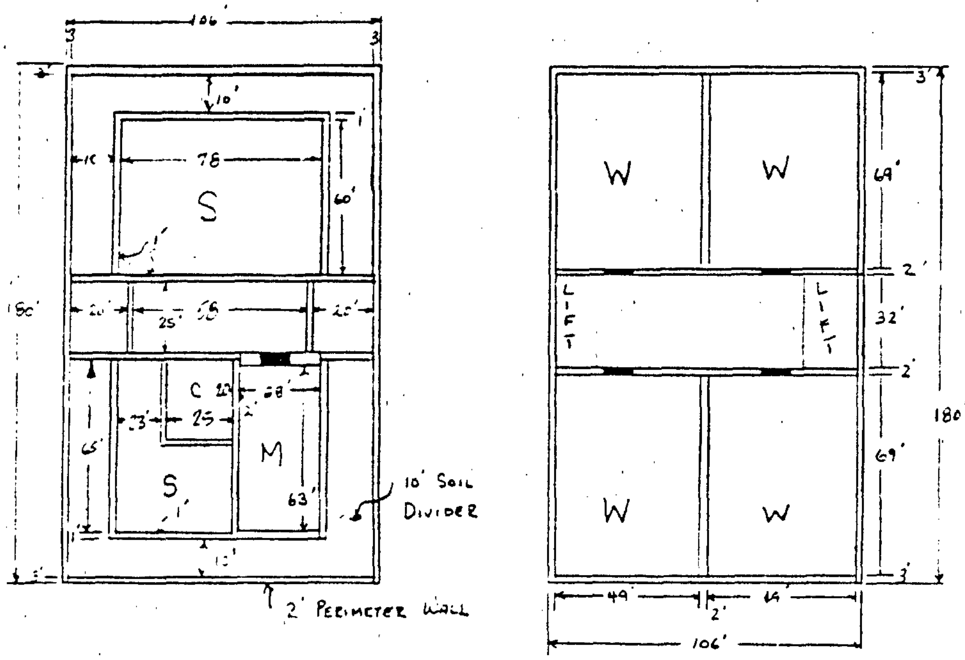
Ceiling Ht.
Ave Wall = 10'
Pac-Man = 15'
Pits = 15'

Floor Area Ranking:		Exterior Area		Int. Area
30 - 32.5K	= 10	8160 - 8680	= 10	5000 - 5500
32.5 - 35	= 9	8680 - 9200	= 9	5500 - 6000
35 - 37.5	= 8	9200 - 9732	= 8	6000 - 6500
37.5 - 40	= 7	9732 - 10260	= 7	6500 - 7000
40 - 42.5	= 6	10260 - 10780	= 6	7000 - 7500
42.5 - 45	= 5	10780 - 11304	= 5	7500 - 8000
45 - 47.5	= 4	11304 - 11828	= 4	8000 - 8500
47.5 - 50	= 3	11828 - 12352	= 3	8500 - 9000
50 - 52.5	= 2	12352 - 12900	= 2	9000 - 9500
52.5 - 55	= 1	12900 - 13400	= 1	9500 - 10000
55 → ∞	= 0	13400 →	= 0	10000 →

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: MW DATE: ______ 19 ____ CHECKED BY: mwb DATE CHECKED: ______ 19 ____



ABOVE GROUND

UNDER GROUND

W = 3351 ft²/ea (Pit Bays)
S = 6840 ft²
M = 1624 ft²
L = 500 ft²/ea
C = 900 ft²

Total Area = 19080 ft² (lower floor) + 13022 (upper floor) = 32,102
Interior wall = 6890 ft²
Exterior wall = 15450
Blast Door No. = 5

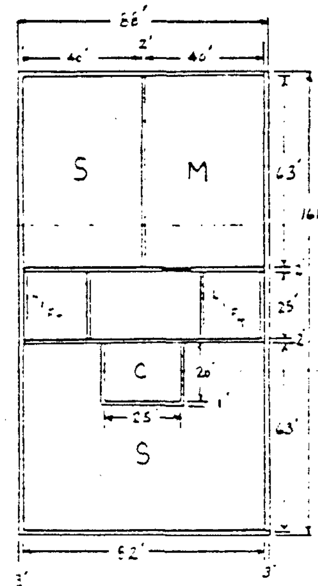
PIT BAYS

10-2

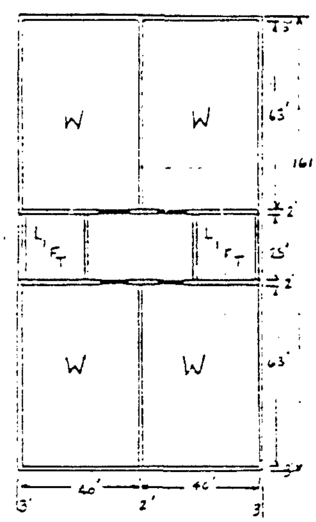
SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LAYOUT
BY: Y.W. DATE: ____ 19 ____ CHECKED BY: nwb DATE CHECKED: ____ 19 ____



Above Ground



Below Ground

[illegible]
Interior Wall = 290(15) = 4350
Exterior Wall = 498(15) = 7470

[illegible]
Interior = 105(10) = 1050
Exterior = 498(10) = 4980

W = 2520 ft²/ea
S = 7119 ft²
M = 2520 ft²
L = 500 ft²/ea
C = 300 ft²
Total Area = 14168 ft²/floor
Interior Wall = 5400 ft²
Exterior Wall = 12450 ft²
Blast Door No = 5

Design 10-1
Stacked Munitions

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092   SPONSOR: CERL
SUBJECT: LAYOUT
BY: [illegible]   DATE: ____ 19 ____   CHECKED BY: MW   DATE CHECKED: ____ 19 ____

		10-1		10-2	
1	Total Floor Area (H)	10	30	10	30
2	Oper. Effiency				
2a	- Bay - Main - Bay (L)	9	9	9	9
2b	- Loadout (M) FL = 10, C.S = 7	8	24	8	24
3	Expandability (L)	7	7	7	7
4	Load Dock Separation (H) <150' = 0; >150' = 10; opp side = 10	10	30	10	30
5	Perimeter Wall Area/Vol. (M)	2	4	0	0
6	Bay Interior Wall Area/Vol. (M)	10	20	7	14
7	"Squareness" of S.M. L &C (M)	10	20	10	20
8	Quantity of Blast Doors (L) 5 Doors = 10; 6 Doors = 9 etc	10	10	10	10
9	Weapons Bay Location (L) (Ext = 8; Int = 10)	8	8	5	5
10	Quantity of Maint. Bays (H) 1 Bay = 10, 2 Bays = 5	10	30	10	30
11	Equipment Needs (H)				
	- [illegible] Needs [illegible]	10	30	7	21
	- [illegible] [illegible]	10	30	7	21
	- [illegible] [illegible] 7	10	30	7	21
			282		224

Multipliers:
H = 3
M = 2
L = 1

Ceiling Ht.
Ave Well = 10'
PAC-MAN = 15'
Pits = 15'

Floor Area Ranking:

30 - 32.5K	= 10
32.5 - 35	= 9
35 - 37.5	= 8
37.5 - 40	= 7
40 - 42.5	= 6
42.5 - 45.	= 5
45 - 47.5	= 4
47.5 - 50	= 3
50 - 52.5	= 2
52.5 - 55	= 1
55 → ∞	= 0

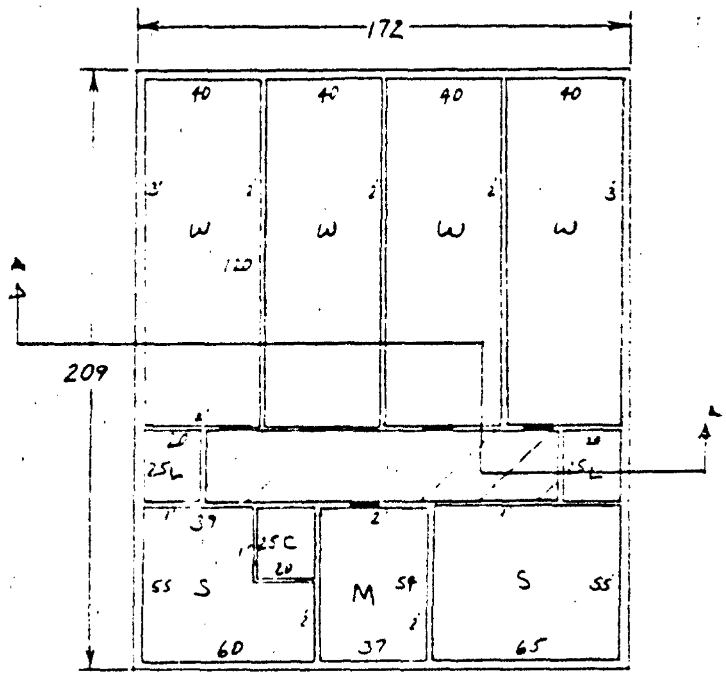
Exterior Area		Int. Area
8160 - 8680	= 10 =	5000 - 5500
8680 - 9200	= 9 =	5500 - 6000
9200 - 9732	= 8 =	6000 - 6500
9732 - 10260	= 7 =	6500 - 7000
10260 - 10780	= 6 =	7000 - 7500
10780 - 11304	= 5 =	7500 - 8000
11304 - 11828	= 4 =	8000 - 8500
11828 - 12352	= 3 =	8500 - 9000
12352 - 12900	= 2 =	9000 - 9500
12900 - 13400	= 1 =	9500 - 10000
13400 →	= 0 =	10000 →

FINAL SIX LAYOUTS SELECTED FOR CONCEPT EVALUATION

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FINAL LAYOUT
BY: MVJ DATE: ____ 19 ____ CHECKED BY: mob DATE CHECKED: ____ 19 ____



BELOW GROUND.

W = 4800 ft²/ea
S = 6329 ft²
M = 1999 ft²
L = 500 ft²/ea
C = 500 ft²
TOTAL AREA = 35948 ft²
PERIMETER WALLS = 7620 ft²
INTERIOR WALLS = 6050 ft²
BLAST DOOR NO = 5

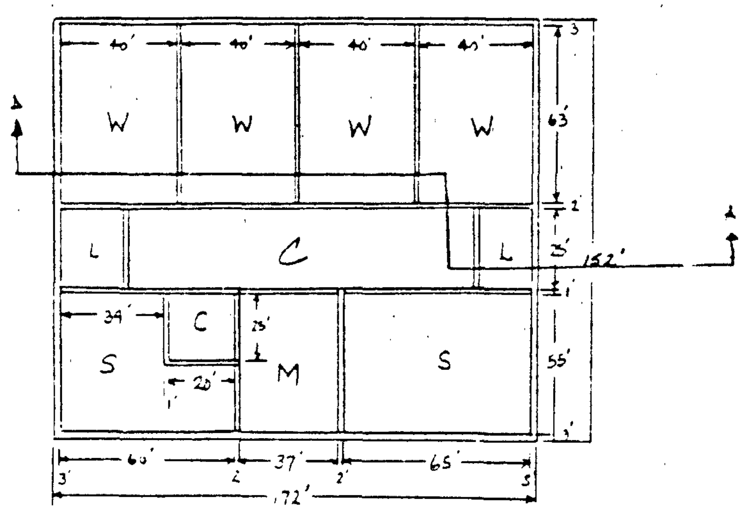
120 x 40 BAYS

DESIGN 1-11

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

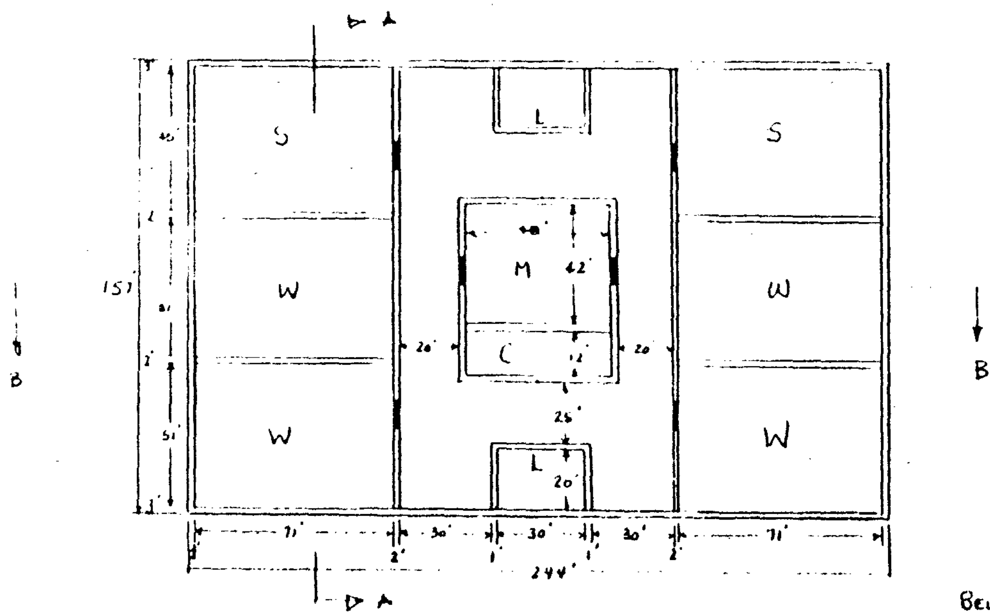
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FINAL LAYOUT
BY: MW DATE: ____ 19 ____ CHECKED BY: mvb DATE CHECKED: ____ 19 ____



W = 2520 ft²/ea
S = 6329 ft²/
M = 2035 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area : 26144 ft²
Interior Wall = 6705 (15' High)
Exterior Wall = 9720 (15' High)

Design 1-12

Stacked Munitions



Below Ground - 30'

PAC MAN DESIGN

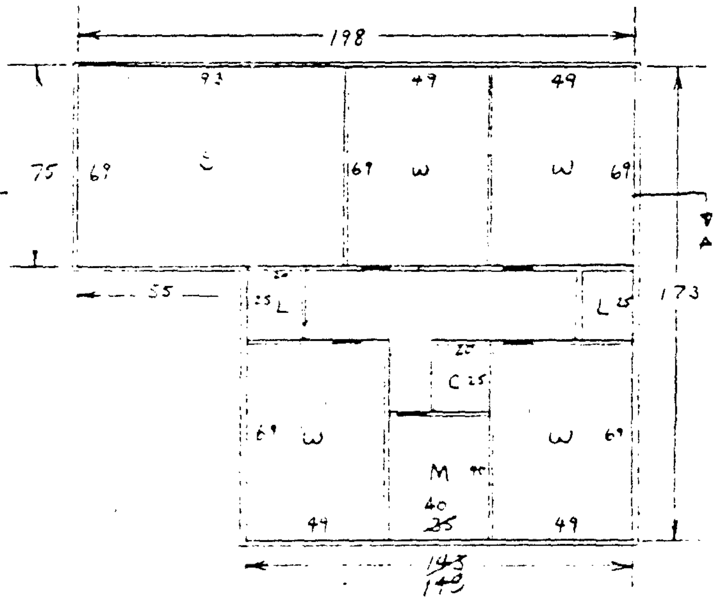
C = 504 ft²
L = 600 ft²/ea
S = 3195 ft²/ea
M = 2016 ft²
W = 3381 ft²/ea
* Total Area = 38308
* Exterior Wall = 12030 (15' Wall)
Internal Wall = 10020 (15' Wall)
Blast Door No = 6

DESIGN No. 2-8
RANKING 212

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

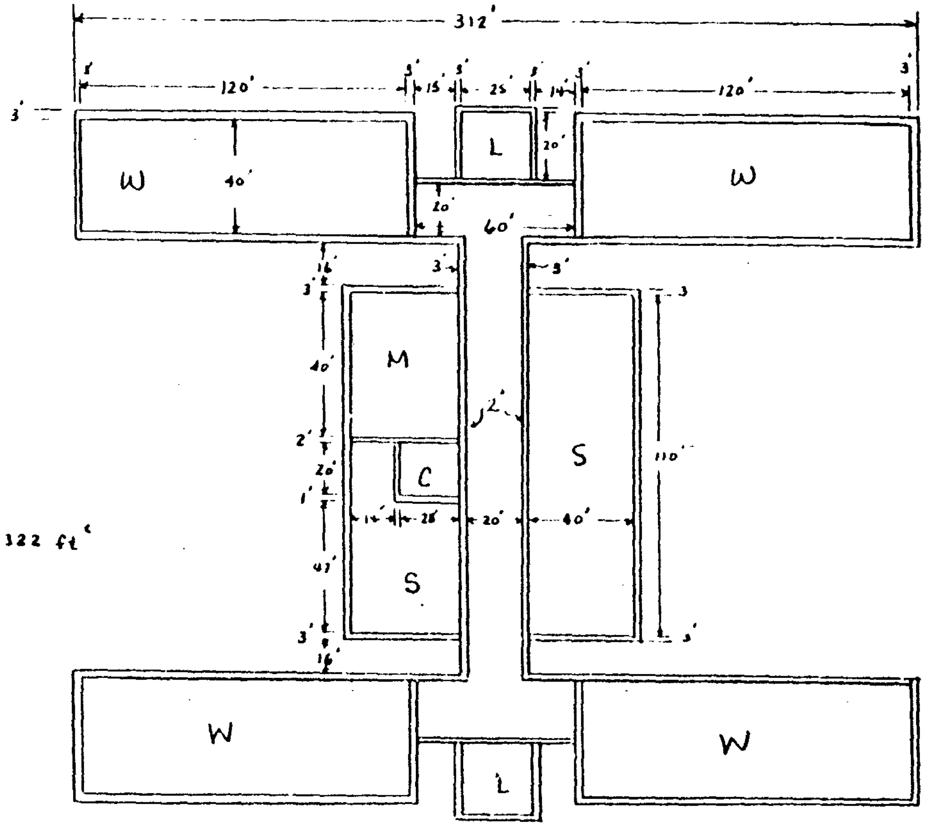
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FINAL LAYOUT
BY: MW DATE: ____ 19 ____ CHECKED BY: mwb DATE CHECKED: ____ 19 ____



ABOVE GROUND

W = 3381 ft²/ea (FIT BAYS)
S = 6417 ft²
M: 1400 ft²
L = 500 ft²/ea
C = 500 ft²
TOTAL AREA = 28,864 ft²
EXTERIOR WALL = 11,130 ft²
INTERIOR WALL = 7605 ft²
BLAST DOOR No = 5

DESIGN 4-5



W = 4800 ft²/ea
L = 500 ft²/ea
C = 500 ft²
S = 6560 ft²
M = 1600 ft²
Total Area = 41322 ft²
120 x 40 Bay

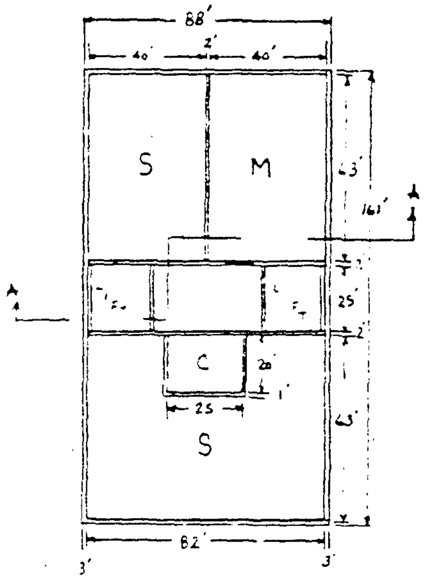
CONCEPT #6 (NO SECTION PROVIDED)

DESIGN 9-1

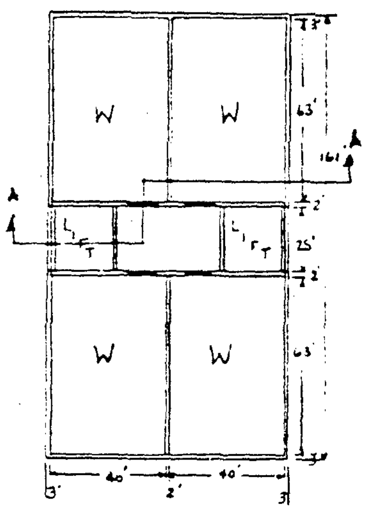
SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FINAL LAYOUT
BY: MW DATE. ____ 19 ____ CHECKED BY: mwb DATE CHECKED: ____ 19 ____



Above Ground



Below Ground

W = 2520 ft²/ea
S = 7119 ft²
M = 2520 ft²
L = 500 ft²/ea
C = 500 ft²
Total Area = 14168 ft²/floor
Interior Wall = 5400 ft²
Exterior Wall = 12450 ft²
Blast Door No. = 5

Underground
Interior Wall = 290 (x15) = 4350
Exterior Wall = 498 (x15) = 7470

Above Grnd
Interior = 105 (10) = 1050
Exterior = 498 (10) = 4980

Design 10-1
Stacked Munitions

APPENDIX 2

CHEMICAL THREAT

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO. 02-7092 SPONSOR: CERL
SUBJECT. INDEX - APPENDIX 2
BY: mwb DATE 9-27 1982 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

APPENDIX 2

CHEMICAL THREAT

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CHEMICAL AGENT THREAT
BY: [illegible] DATE: 8-18 1982 CHECKED BY: ____ DATE CHECKED: ____ 19 ____

BLISTER AGENTS

Blister agents are primarily chlorinated organic compounds often containing sulphur and nitrogen. Some can be classified as chlorinated amines. Blister agents and nerve agents fall into the same classes as many pesticides and herbicides. Blister agents irritate and/or poison cells in the eyes, lungs and skin. Effects are usually somewhat delayed (several hours). There is very little immediate pain upon contact. The agent causes severe nose and throat irritation, eye damage, and skin blistering and swelling. When death occurs, it is usually the result of infection. Lethal doses are shown in Table 1. Blister agents include mustard (5-6 types), phosgene oxime (CX), and Lewisite (L). Mustard was used during World War I. Many of the later blister agents are odorless. The duration of effectiveness varies from agent to agent.

The concentration at which minor physiological effects begin is generally taken to be 4 $\mu g/cm^2$ for mustard agent HD (Reference 1).

1. MIL-STD-282, "Filter Units, Protective Clothing, Gas-Mask Components and Related Products: Performance Test Methods," Department of Defense, 28 May 1956 with change 2 dated 3 December 1974.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 2 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CHEMICAL AGENT THREAT
BY: mwt DATE: 8-18 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

NERVE AGENTS

Nerve agents can be referred to as organophosphorus compounds. They are extremely toxic and fast acting, as shown in Table 1. A few tens of milligrams of liquid agent can cause death in less than 15 minutes. Very minute concentrations around the eye will lead to marked miosis. The nerve agents enter the body through the respiratory system, the eyes, or exposed skin. Both liquid and vapor forms will rapidly penetrate the skin. Nerve agents act by upsetting the balance between the sympathetic and parasympathetic nervous systems, resulting in convulsions, coma, and death. Some examples of nerve agents are tabun (GA), sarin (GB), soman (GD) and agent VX (or VR55). Nerve agents have a relatively long duration of effectiveness (days as opposed to hours). Agents like VX are absorbed by vegetation and can have long-term effects.

The concentration at which minor physiological effects begin is generally taken to be 4 $\mu g/cm^2$ for agent VX (2). For years, the maximum acceptable concentration for GB was set at 1.25 $\mu g/cm^2$ (1), and a similar value was assumed for thickened GD (2). However, tests conducted in 1977 indicate that concentrations of GB as high as 4 to 5 $\mu g/cm^2$ preclude physiological effects, and 10 $\mu g/cm^2$ can be used as the break point for GB if a slight cholinesterase despression can be tolerated (3).

(2) McGrath, Anna S., et al., "Evaluation of Candidate Agent Protective Materials for Use by United States Air Force Personnel (u)," U.S. Army Chemical Systems Laboratory, ARCSL-SP-79006, ADC017685L, April 1979, Confidential

(3) Jaynes, Capt. Edgar N., "Report of Active Duty Training," DF, DRDAR-CLW-P, through Chief, Individual Protection Branch, and Chief, Physical Protection Division to Director of Personnel and Force Development, U.S. Army Chemical Systems Laboratory, 17 June 1977.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 3 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CHEMICAL AGENT THREAT
BY: TMWG DATE: 8-18 1982 CHECKED BY: DATE CHECKED: 19

BLOOD AGENTS

Blood agents prevent transfer of oxygen from the blood to the body tissue. Death occurs as a result of interference with the liver, kidneys and lungs. Blood agents include hydrogen cyanide (AC), cyanogen chloride (CK), and arsine (SA). Blood agents must be disseminated as a gas. They are absorbed into the body primarily by breathing, and have a short effectiveness duration. Hydrogen cyanide may cause death within 15 minutes. Arsine, on the other hand, may take anywhere from several hours to several weeks to develop maximum effects. Lethal doses are summarized in Table 1.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 4 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CHEMICAL AGENT THREAT
BY: [illegible] DATE: 8-16 19 82 CHECKED BY: DATE CHECKED: 19

CHOKING AGENTS

Choking agents can be characterized in general terms as halogenated compounds of a type that readily hydrolize in the presence of moisture in the respiratory system to form hydrochloric acid, thus irritating and inflaming the nose and throat membranes causing swelling. The lungs fill with fluid. Death occurs from lack of oxygen. Lethal doses are given in Table 1. Examples of such agents are phosgene (CG) and diphosgene (DP). Phosgene was used extensively in World War I. At least 80 percent of the chemical agent fatalities in this war were caused by phosgene. It has a low persistence rating. A delay of three or four hours will typically occur between exposure and the onset of disabling symptoms for the concentrations expected on the battlefield. Most deaths will occur within 24 hours. The choking agents must be disseminated as gases to be effective since they enter the body primarily through the respiratory system.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 5 OF 17

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CHEMICAL AGENT THREAT
BY: [illegible] DATE: 8-18 1982 CHECKED BY: DATE CHECKED: 19

TABLE 1. CHEMICAL AGENT LETHAL DOSES

Agent	Exposure Conditions	Median Lethal Dosage (mg-min/m^3)
Blister Agents		
• HD distilled mustard	Inhalation	1,500
	Skin absorption	10,000
• HN-3 nitrogen mustard	Inhalation	1,500
	Skin absorption	10,000 (est)
• L lewisite	Inhalation	1,200-1,500
	Skin absorption	100,000
Nerve Agents		
• GA tabun	Inhalation (resting)	400
• GB sarin	Inhalation (resting)	100
	(mild activity)	70
• GD soman	Inhalation (resting)	GB-GA range
Blood Agents		
• AC hydrogen cyanide	Inhalation	Wide variation with concentration γ
		2,000 for γ = 200 mg/m^3
		4,500 for γ = 150 mg/m^3
• CK cyanogen chloride	Inhalation	11,000
• SA arsine	Inhalation	5,000
Choking Agents		
• CG phosgene	Inhalation	3,200
• DP diphosgene	Inhalation	3,200

Source: TM 3-215, "Military Chemistry and Chemical Agents," Departments of the Air Force and Army, Washington, D.C., December 1963 with change 1 dated 16 March 1965.

PROJECT NO.: 02-7092 SPOI .R. CERL
SUBJECT: Air Supply Arrangements
BY: mmt DATE 7-23 19 82 CHECKED BY ______ DATE CHECKED: ______ 19 ______

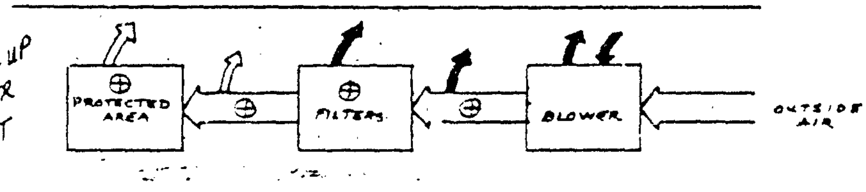
Air Supply options

1. Blowthrough system, no recirculation
2. Recirculation air through A/C only.
3. Recirculation air through a particulate filter and A/C
4. Recirculation air through CBR filters and A/C.
5. Parallel banks with detector and auto switching.

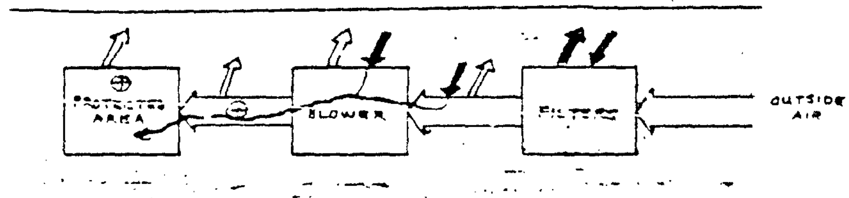
Positive Pressure Systems:

⇧⇩ - leaks
⊕ - highest pressure area
RED - contaminated air.

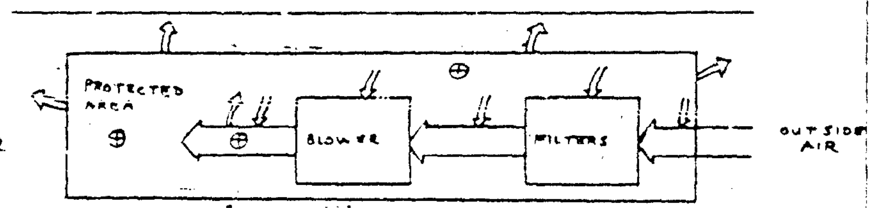
OK
MUST SUIT-UP FOR FILTER CHANGEOUT



WILL NOT PROTECT

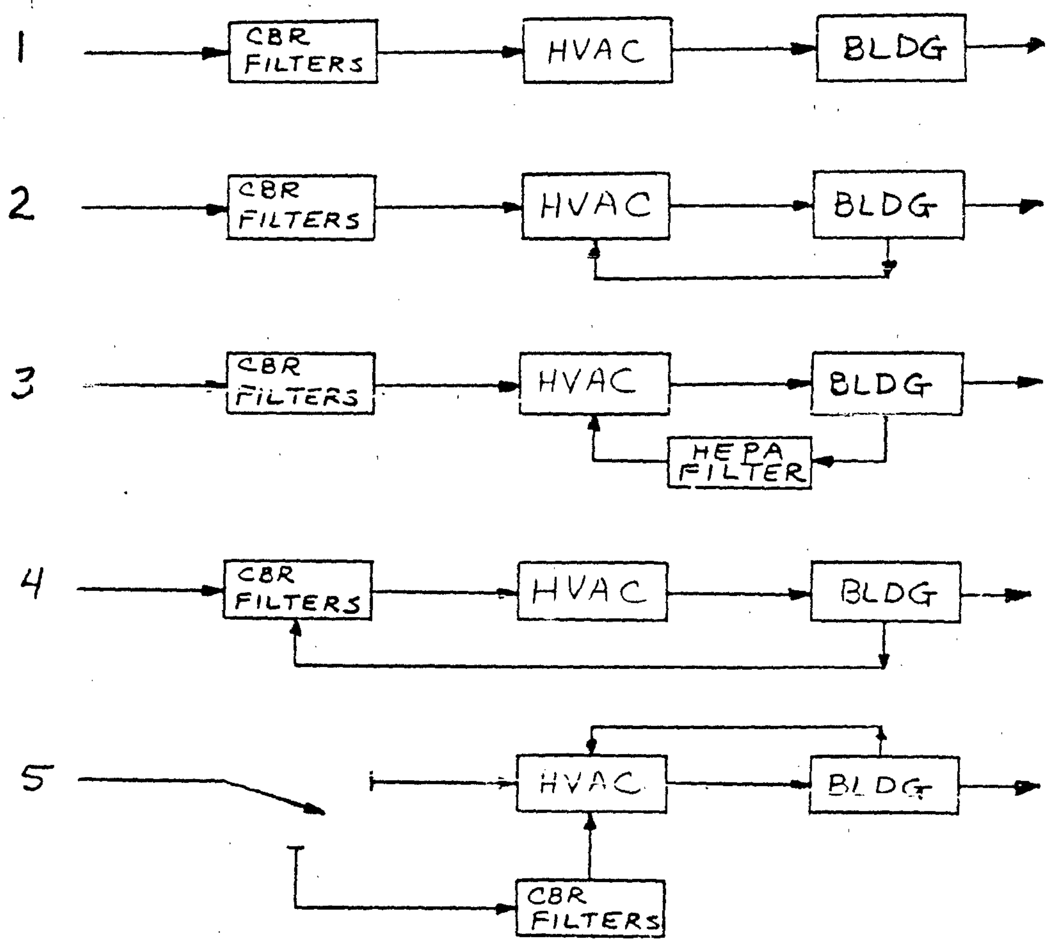


OK UNTIL FILTER CHANGEOUT OR BLOWER SHUTDOWN



PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: AIR SUPPLY ARRANGEMENTS
BY: [signature] DATE: 7-23-1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

AIR SUPPLY OPTIONS

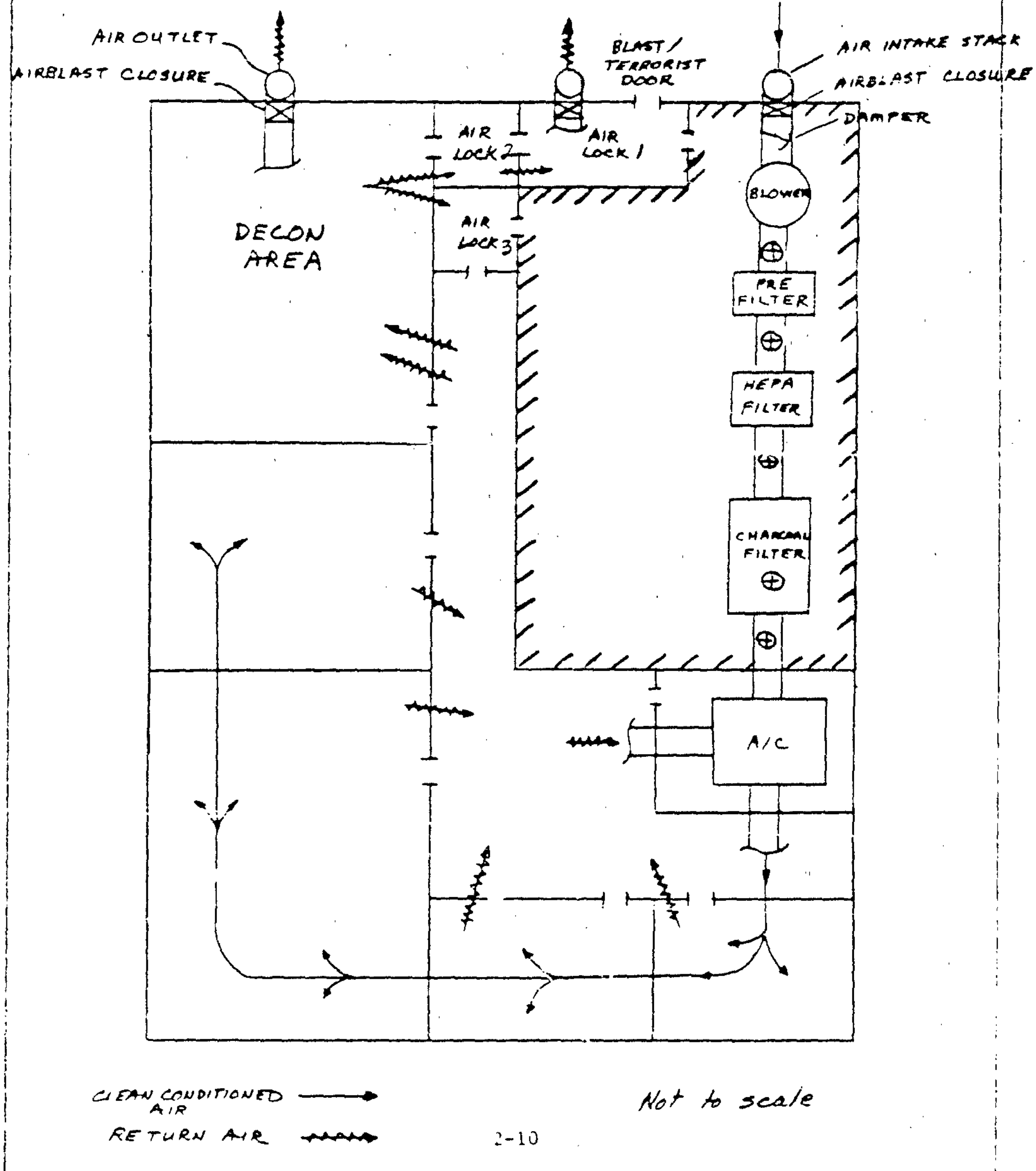


*CBR = CHEMICAL/BIOLOGICAL/RADIOLOGICAL
HVAC = HEATING, VENTILATING AIR CONDITIONING

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 8 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: AIR SUPPLY ARRANGEMENTS
BY: mwb DATE: 7-26 1982 CHECKED BY: ____ DATE CHECKED: ____ 19 ____



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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 9 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CHEMICAL DEFENSE ENSEMBLE
BY: nwt DATE: 8-17 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

U.S. Army Personal Protection Equipment

1. Mask, chemical - biological: Field, M17A1 FSN 4240-00-926-4201

   Designed to protect face, eyes, & respiratory tract
   Self-contained drinking system
   Voicemitter

2. Filter element, M13A2 FSN 4240-00-165-5026

   Charcoal canister

3. Hood, CB Mask: Field, ABC-M6A2 FSN 4240-00-999-0420

   Designed to protect head and neck
   Butyl coated nylon

4. Suit, chemical protective NSN 8415-00-177-5008

   Charcoal impregnated material

5. Footwear covers, chemical protective NSN 8430-01-021-5978

   Butyl rubber overboot
   Worn over standard leather combat boot

6. Glove set, chemical protective NSN 8415-00-033-3518

   Butyl rubber gloves
   25 mil thick
   Cotton inserts.

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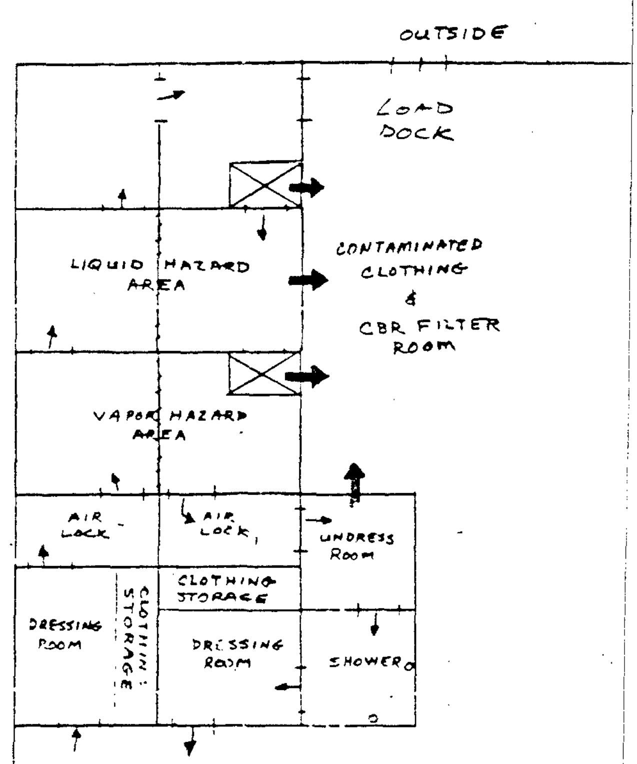
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 10 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CONTAMINATION CONTROL AREA
BY: nwb DATE: 8-4-1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

DON/DOFF FACILITY



46' x 20' = 920
16' x 8' = 128
1048 ft²

protected 36x20 = 720
16 x 8 = 128
848 ft²

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 11 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Don/Doff Procedures
BY: [illegible] DATE: 8-11 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

TYPICAL DOFF PROCEDURES

DOORWAY TO LIQUID HAZARD AREA:

1. Remove overboots
2. Shuffle feet and hands in Fullers Earth
3. Proceed into Liquid Hazard Area.

INSIDE LIQUID HAZARD AREA:

4. Dust mask with Fullers Earth
5. Remove combat boots and pull on a clean plastic tube sock before touching floor.
6. Remove helmet
7. Remove hood
8. Remove outer ensemble pants and shirt with help from another person. Do not remove gloves or gas mask.
9. Dust hands, feet, mask with Fullers Earth
10. Proceed to doorway between Liquid and Vapor Hazard Areas.

DOORWAY TO VAPOR HAZARD AREA:

11. Have LHA attendant peel off rubber gloves, and pull a clean tube sock over each hand.
12. Hold breath, close eyes while attendant removes mask and replaces with a clean one.
13. Clear and seal the mask.
14. Proceed to Vapor Hazard Area.

INSIDE VAPOR HAZARD AREA:

15. Replace tube socks with clean ones (hands and feet)
16. Remove charcoal undergarment.
17. Proceed to Airlock entry

DOORWAY TO AIRLOCK:

18. Pass hand and foot plastic tube socks back into VHA as you step into the airlock.
19. Remove ~~cotton~~ glove inserts and pass them back into VHA.
20. Close Airlock door.

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 12 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Don/doff Procedures
BY: mwt DATE: 9-11 1982 CHECKED BY: DATE CHECKED: 19

TYPICAL DOFF PROCEDURES (CON'T)

INSIDE AIRLOCK:

21. Set purging air timer for 2 minutes.
22. When timer rings open door to undress room (not the door to the VHA).
23. Enter the Undress Room.

INSIDE THE UNDRESS ROOM:

24. Remove socks
25. Remove underwear
26. Set purging air timer for 2 minutes.
27. When timer rings, remove mask
28. Exit into shower room

INSIDE SHOWER ROOM:

29. Take hot shower with liberal use of soap.
30. Wash hair
31. Dry and step into dressing room.

INSIDE DRESSING ROOM

32. Full body scan with chemical agent detector/alarm.
33. Don clean work clothes.
34. Enter protected shelter area.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 13 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: wind pressures
BY: rwb DATE: 8-2-1982 CHECKED BY: DATE CHECKED: 19

Dynamic wind pressure = $p_w = \frac{1}{2} \rho v^2$

$\rho_{air} = \frac{0.001293\ H}{76(1+0.00367\ t)}$ gm/ml per CRC Hdbk of Physics & Chemistry 1966-67, pg F-8

H = atmospheric pressure (cm of Hg)
t = temperature (°C)

1 gm/ml = 62.42621 lbm/ft³
= 0.03612628 lbm/in³ where 1 lbm = $\frac{1\ lbf}{g}$

1 mile/hr = 1.466667 ft/sec
= 17.6 in/sec

g = acceleration due to gravity = 32.1725 ft/sec² @ sea level, 45°N lat.
= 386.070 in/sec²

1 lbf/in² = 27.68068 inH₂O at 4°C

$\boxed{\text{25 mph wind}}$ @ 4°C, 76.0 cm Hg

$\rho_{air} = \frac{(0.001293)(76)}{(76)[1+(0.00367)(4)]} = 0.00127429$ gm/ml $= .00004604$ lbm/in³

$g = 386.070$ in/sec²

$\rho_{air} = (.00004604)/(386.070)$ $\left(\frac{lbf}{in^3}\right)/\left(\frac{in}{sec^2}\right)$

$= 1.1925 \times 10^{-7}$ lbf·sec²/in⁴

$v = 25$ miles/hr $= 440$ in/sec

$p_w = \left(\frac{1}{2}\right)(1.1925 \times 10^{-7})(440)^2$ $\frac{lbf\text{-}sec^2}{in^4} \cdot \frac{in^2}{sec^2}$

$= 0.011543$ lbf/in²

$= 0.32$ in H₂O

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 14 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Wind pressures
BY: [illegible] DATE: 8-2-1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

$\boxed{25\text{ mph wind}}$ @ 21.1°C (70°F), 76.0 cm Hg

$\rho_{air} = \dfrac{(0.001293)(76)}{(76)[1+(.00367)(21.1)]} = 0.00120007 \text{ gm/ml} = 4.335 \times 10^{-5} \text{ lbm/in}^3$

$g = 386.070 \text{ in/sec}^2$

$\rho_{air} = (4.335 \times 10^{-5})/(386.070) = 1.1229 \times 10^{-7} \text{ lbf-sec}^2/\text{in}^4$

$v = 25 \text{ miles/hr} = 440 \text{ in/sec}$

$p_w = (\tfrac{1}{2})(1.1229 \times 10^{-7})(440)^2$

$= 0.010869 \text{ lbf/in}^2$

$\approx 0.30 \text{ in } H_2O$

$\boxed{50\text{ mph wind}}$ @ 21.1°C (70°F), 76.0 cm Hg.

$\rho_{air} = 1.1229 \times 10^{-7} \text{ lbf-sec}^2/\text{in}^4$

$v = 50 \text{ miles/hr} = 880 \text{ in/sec}$

$p_w = \tfrac{1}{2}(1.1229 \times 10^{-7})(880)^2$

$= 0.043479 \text{ lbf/in}^2$

$\approx 1.20 \text{ in } H_2O$

[Mears, Merton D., "Handbook on Collective Protection," ARCSL-SP-79003, US Army Chemical Systems Laboratory, August 1979]

Note: Reference 1 states on pg 12 that

"... it has been arbitrarily established that no area of a stationary protected system that is adjacent to a possibly contaminated area should be below 0.3 in. H_2O overpressure. This is equivalent to the impact pressure of a 25 mph wind on a flat vertical wall normal to the wind direction. The effectiveness of an agent attack diminishes rapidly as the wind approaches 25 mph."

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 15 OF 17

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: PURGING AIR REQUIREMENTS
BY: mwb DATE: 8-6 19 82 CHECKED BY: DATE CHECKED: 19

DOFF

Reference * calls for a 2 minute stay in the airlock, and a 2 minute stay in the undressing area.

Assume a 1000:1 reduction in concentration is required during the T = 2 minute period

Airlock Volume = 5' x 10' x 10' = 500 ft^3 = V

$$\frac{C}{C_0} = e^{-\frac{QT}{V}}$$

$$\frac{1}{1000} = e^{-\frac{Q(2)}{500}}$$

$$.001 = e^{-0.004Q}$$

$$Q = -\frac{\ln .001}{0.004}$$

$$\boxed{Q = 1727} \text{ cfm.}$$

Undressing Area Volume = 8' x 8' x 10' = 640 ft^3 = V

$$\frac{C}{C_0} = e^{-\frac{QT}{V}}$$

$$\frac{1}{1000} = e^{-\frac{Q(2)}{640}}$$

$$.001 = e^{-0.003125Q}$$

$$Q = -\frac{\ln .001}{.003125}$$

$$\boxed{Q = 2210} \text{ cfm}$$

* Sears, Col. William J., "An Evaluation of USAF and RAF Aircrew Chemical Defense Shelter Processing Procedures," SAM-TR-81-5 USAF School of Aerospace Medicine, February 1981, FOUO

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 16 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: AIRFLOW RATE RQMTS
BY: [illegible] DATE: 8-25 1982 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

Reference *, pg 136 indicates
20 room air changes per hour
is the accepted standard for conventional clean rooms

$\therefore$ Flow rate $= 20V$ ft^3/hr

$= \frac{20V}{60}$ ft^3/min

$= \frac{V}{3}$ ft^3/min where V is the room volume.

If this criteria were applied to the 848 ft^2 floor space of the decontamination control area, the resulting flow rate required (assuming a 10 ft ceiling height) is found as follows:

$$V = (848)(10) = 8480\ ft^3$$

$$Q = \frac{8480}{3} = 2827\ ft^3/min$$

* Austin, Philip R., Design and Operation of Clean Rooms, Business News Publishing Co., Detroit, MI, 1970.

assume 10' ceiling height all parts of contamination control area.

Assumed pressurization requirements:

	inches H_2O	Volume (ft^3)
• liquid hazard area	0.3	10 X 20 X 10 = 2000
• vapor hazard area	0.4	10 X 20 X 10 = 2000
• 2 airlocks, undress room, shower	0.5	5X20X10 + 16 X 8 X 10 = 2280
• 2 dressing rooms, 2 clothing storage areas	0.6	11 X 20 X 10 = 2200

Compute required "static" mass of air needed in each area to produce the desired pressures.

Methodology:

Equation of state for P-V-T behavior of gases at low density

$$PV = mRT$$

$m = \frac{PV}{RT}$ where m = total mass of the enclosed air (lbm)

P = pressure in enclosed area (lbf/ft^2)

V = total enclosed volume (ft^3)

T = air temperature (°R)

R = Universal gas constant in mass units
R_{air} = 53.34 (ft-lbf)/(lbm-R°)

Useful conversion factors

g = 32.174 ft/sec^2

lbf = (lbm)(g) = 32.174 lbm-ft/sec^2

°R = °F + 459.67

1 in H_2O (39.2°F) = 5.20218 lbf/ft^2 = 0.03612628 lbf/in^2

1 in H_2O (60°F) = 5.1982276 lbf/ft^2 = 0.03609908 lbf/in^2
1 in H_2O (78°F) = 5.1948819 lbf/ft^2 (linear extrapolation)

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 18 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: SHELTER PRESSURIZATION
BY: nwb DATE: 8-25 1982 CHECKED BY: DATE CHECKED: 19

Liquid Hazard Area

$P = 0.3 \text{ in } H_2O$
$= (0.3)(5.1948819) \text{ lbf/ft}^2 \text{ at } 78°F$
$= 1.5584646 \text{ lbf/ft}^2 \text{ at } 78°F$

$V = 2000 \text{ ft}^3$

$R = 53.34 \text{ (ft-lbf/lbm-°R)}$

$T = 78°F$
$= 78 + 459.67 \text{ °R}$
$= 537.67 \text{ °R}$

$$m = \frac{PV}{RT} = \frac{(1.5584646)(2000)}{(53.34)(537.67)} = 0.1087 \text{ lbm}$$

Vapor Hazard Area

$P = 0.4 \text{ in } H_2O$
$= (0.4)(5.1948819) \text{ lbf/ft}^2 \text{ at } 78°F$
$= 2.0779528 \text{ lbf/ft}^2 \text{ at } 78°F$

$V = 2000 \text{ ft}^3$

$R = 53.34 \text{ (ft-lbf/lbm-°R)}$

$T = 78°F$
$= 537.67 \text{ °R}$

$$m = \frac{PV}{RT} = \frac{(2.0779528)(2000)}{(53.34)(537.67)} = 0.1449 \text{ lbm}$$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO 19 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: SHELTER PRESSURIZATION
BY: mob DATE: 8-25 1982 CHECKED BY: DATE CHECKED: 19

2 airlocks + undress room + shower

$P = 0.5$ in H_2O
$= (0.5)(5.1948819)$ lbf/ft² at 78°F
$= 2.597441$ lbf/ft² at 78°F

$V = 2280$ ft³

$R = 53.34$ (ft-lbf / lbm·R°)

$T = 78°F$
$= 537.67°R$

$$m = \frac{PV}{RT} = \frac{(2.597441)(2280)}{(53.34)(537.67)} = 0.2065 \text{ lbm}$$

APPENDIX 3

ARCHITECT ENGINEER NARRATIVE

TABLE OF CONTENTS

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

MUNITIONS STORAGE CONCEPTS FOR USE IN FLAT TERRAIN
FACILITY CONCEPTS

INTRODUCTION

This facility concepts study has been prepared under a subcontract agreement with Southwest Research Institute in conjunction with their project to develop munitions storage concepts for use in flat terrain for the Department of the Army, Construction Engineering Research Laboratory at Champaign, Illinois.

The diagrams, descriptive narratives and other information contained in this report present six conceptual solutions for a weapons storage facility in flat terrain based on criteria and guidelines provided by Southwest Research Institute, including blast wall design data and chemical hazard control measures. Close coordination between the Southwest Research Institute and Bernard Johnson Incorporated project teams has been maintained to evaluate all conceptual solutions and ideas for feasibility of construction as well as for functional and security requirements.

This report presents the six conceptual facility plans, as coordinated with the Southwest Research project team. It includes, in addition to conceptual facility diagrams, narrative descriptions of proposed building systems, budgetary estimates of probable construction costs and a comparative analysis of the six concepts.

It is intended that this conceptual study be preliminary to and establish a basis for a definitive architectural/engineering design program.

The facility study focuses primarily on requirements established by Southwest Research Institute during initial investigation of the criteria and project requirements. Basic provisions of all concepts respond to requirements for storage or warehousing of munitions, handling of the munitions within the storage facility, security of the storage facility from accidental or intended damage or destruction and personnel safety.

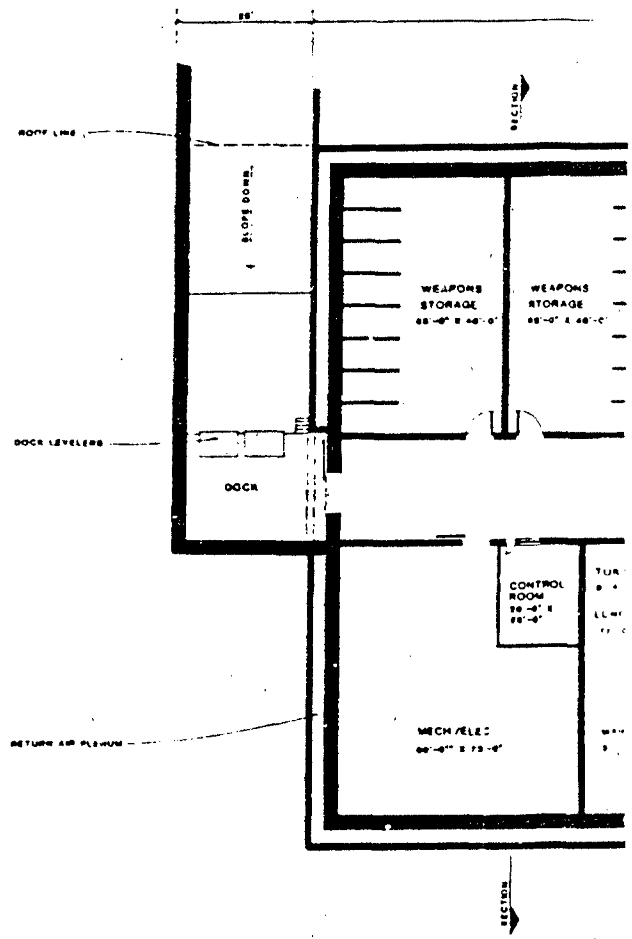
Each concept was developed around four munitions storage bays or rooms, a munitions maintenance/service room, control room, load out docks and contamination control area. Appropriate provisions were then made for circulation, support and utilities. Backup utility systems are included in all concepts to permit continuation of operations should the primary system be lost or fail.

There are no site related considerations included in this study since a definitive site was not identified. Building site preparation and foundation provisions were based on readily available information and previous experiences in designing foundations for similar facilities in the Houston-Galveston, Texas vicinity. It should be recognized that subsurface soil conditions may vary widely within a given area.

Estimates of probable construction costs are based on readily available unit costing factors for the type of facility described and adjusted with assumed contingency factors based on current experience in Houston, Texas. Escalation is not included in estimates since the schedule for starting construction is unknown.

Both objectives and subjective factors were utilized in a comparative analysis of six concepts to determine the most appropriate concepts for further consideration.

SECTION I



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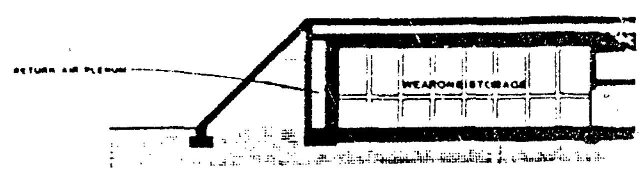

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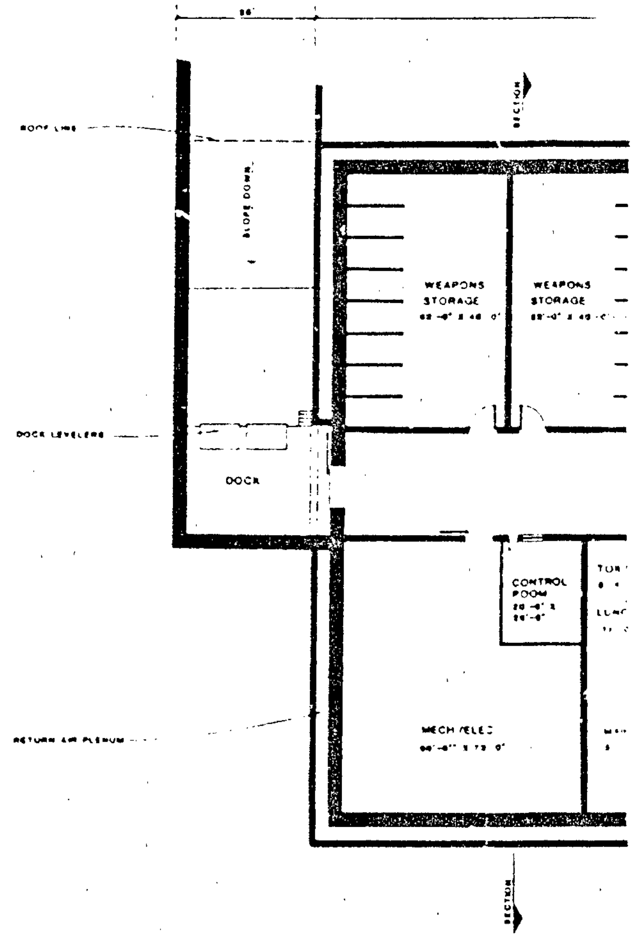

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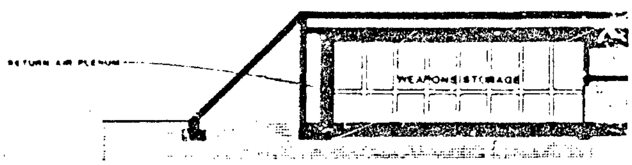

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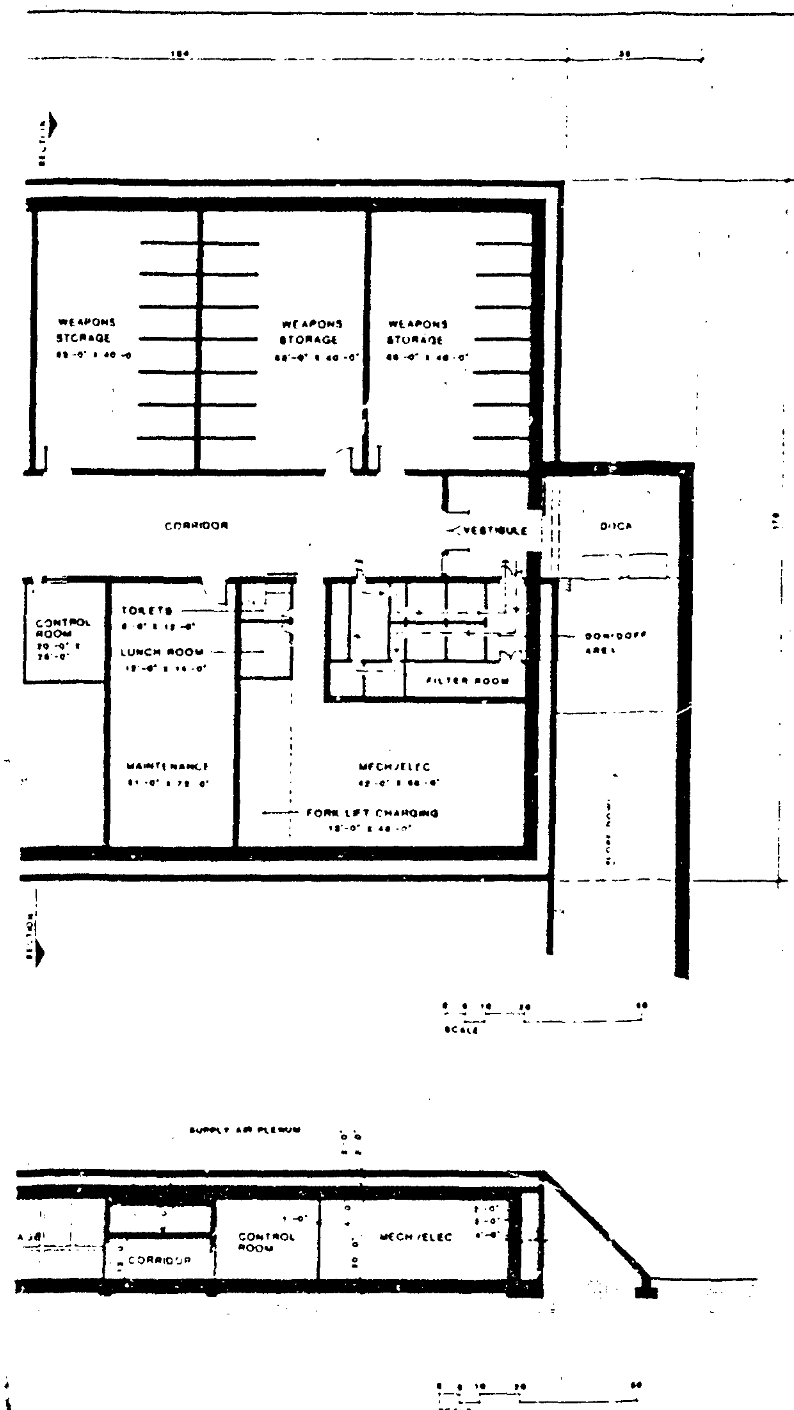

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AMMUNITION STORAGE FACILITY
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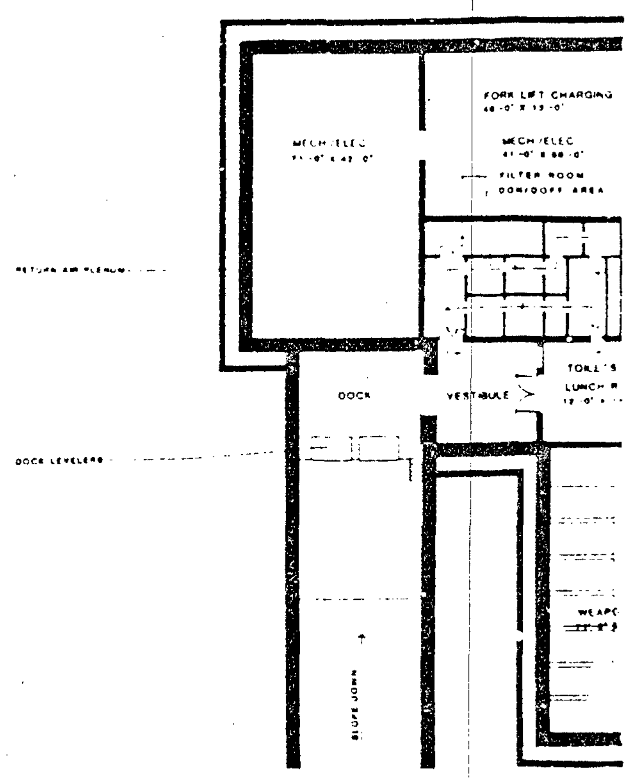

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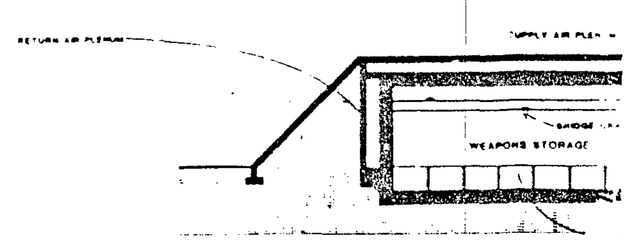

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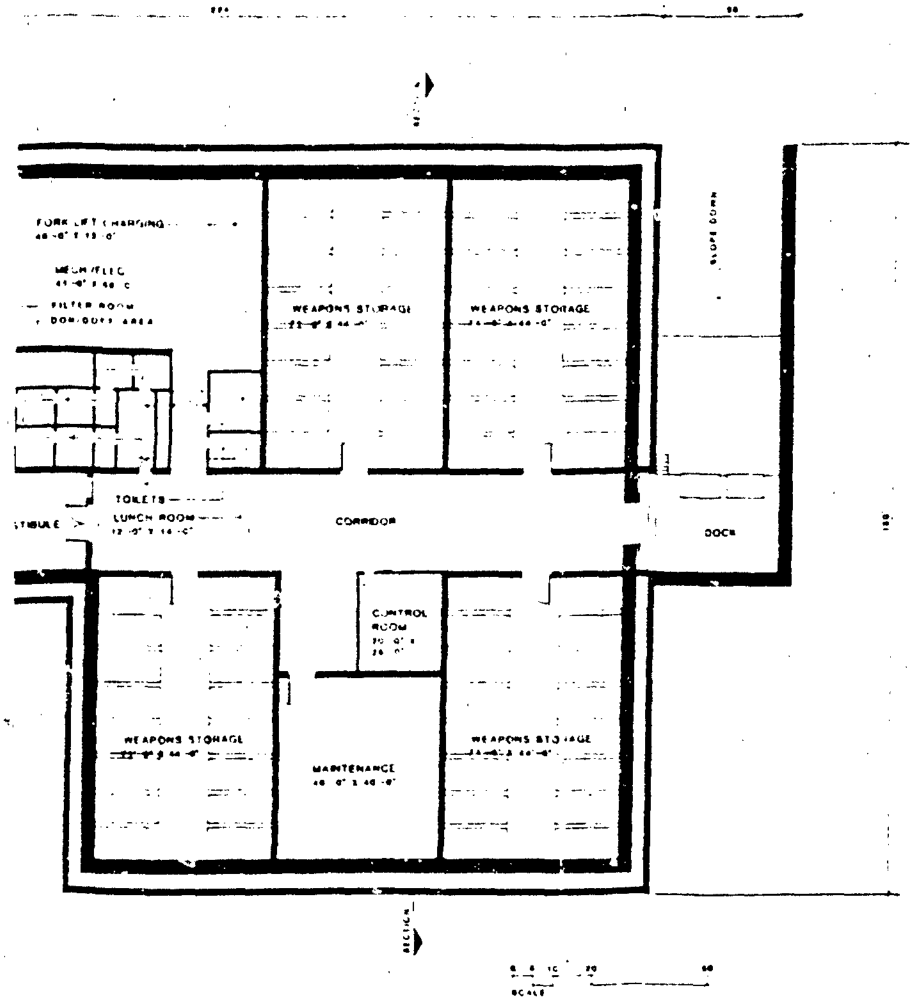

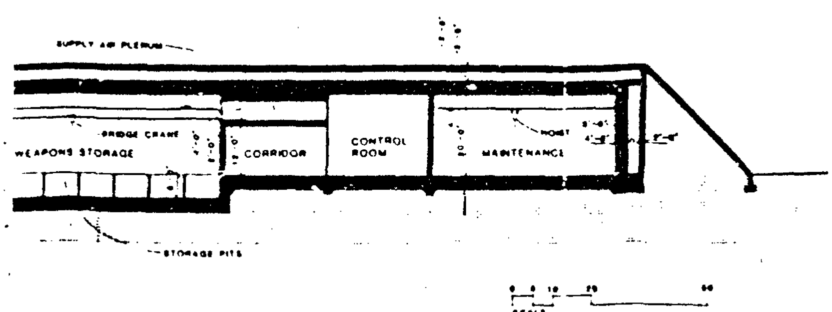

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AMMUNITION STORAGE FACILITY

CONCEPT NUMBER 2

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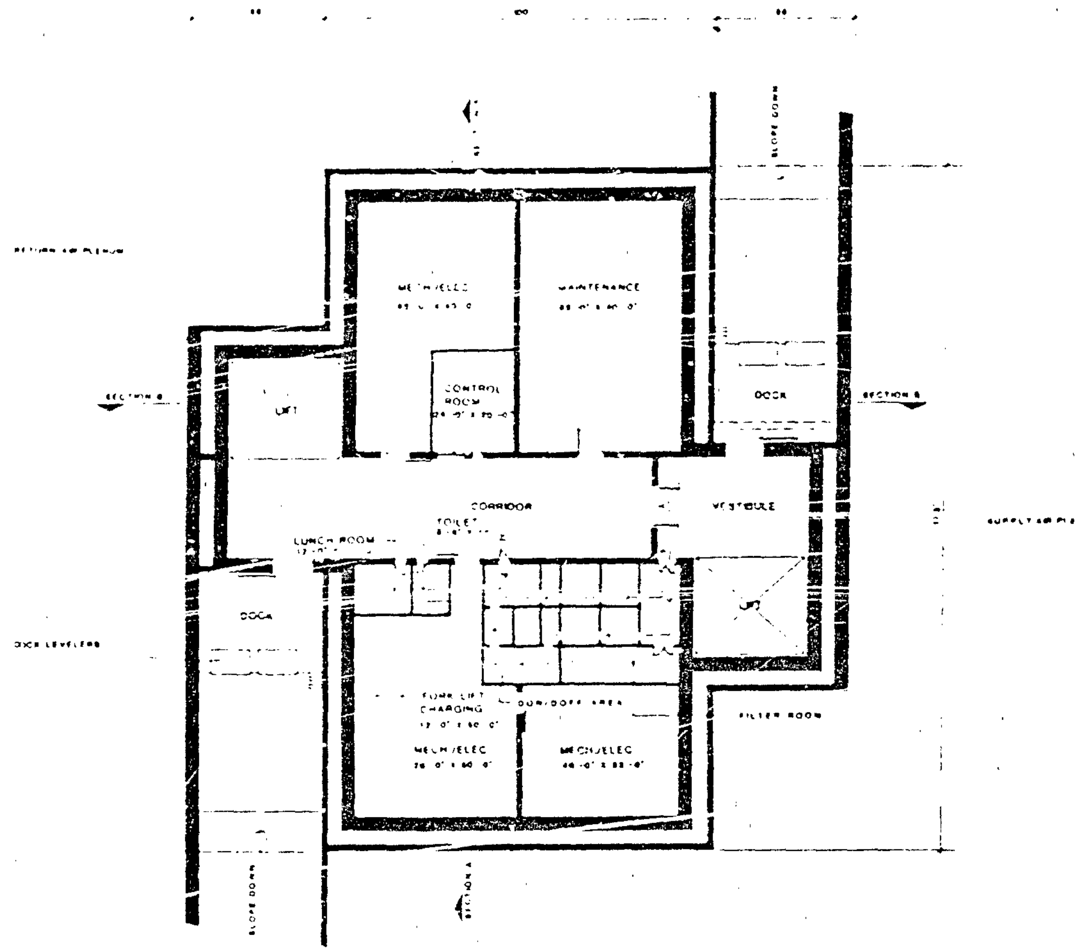

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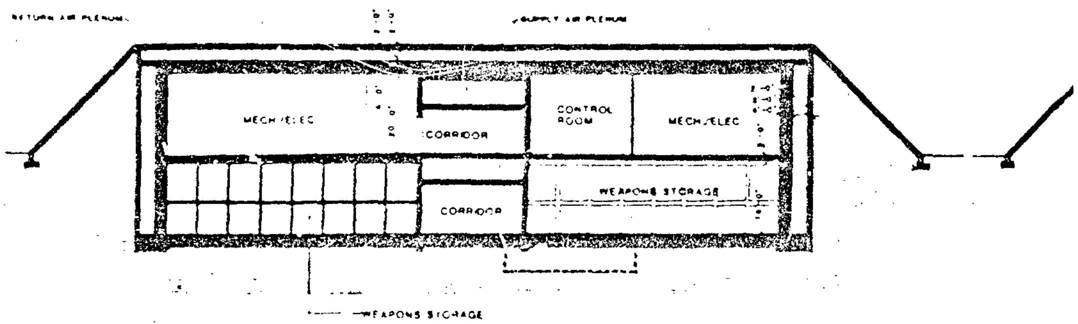

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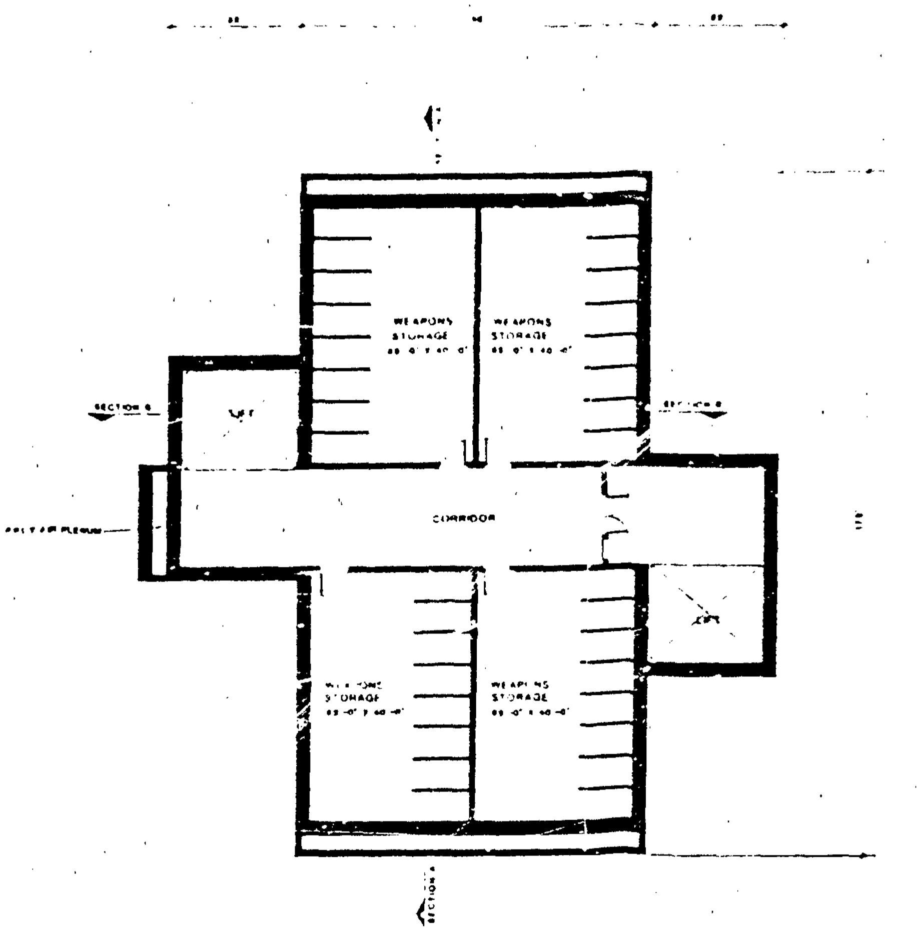

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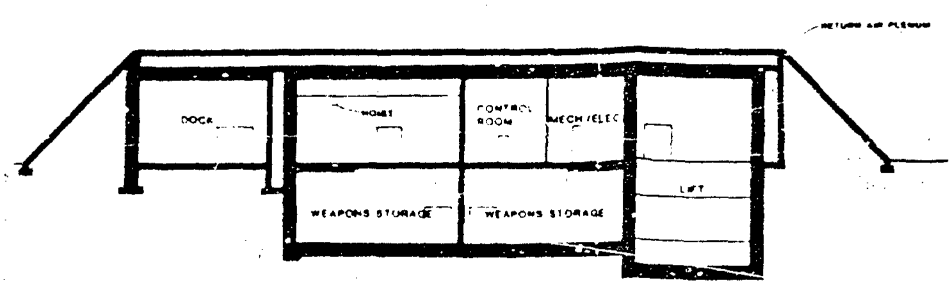

SECTION B
CONCEPT NO. 3

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AMMUNITION STORAGE FACILITY
CONCEPT NUMBER 3

PLAN AND SECTION

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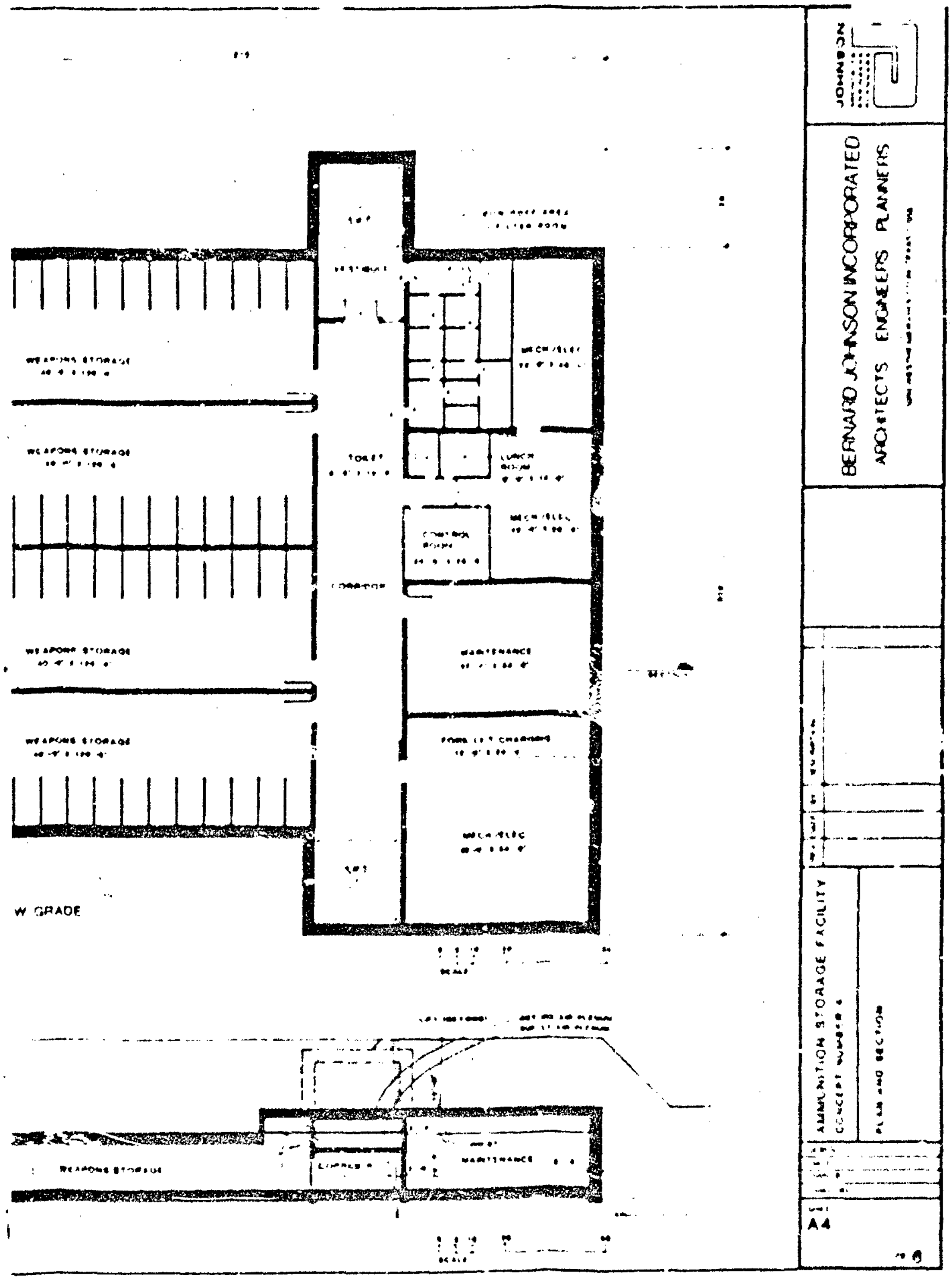
A3
of 6



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CORRIDOR
CONTROL ROOM
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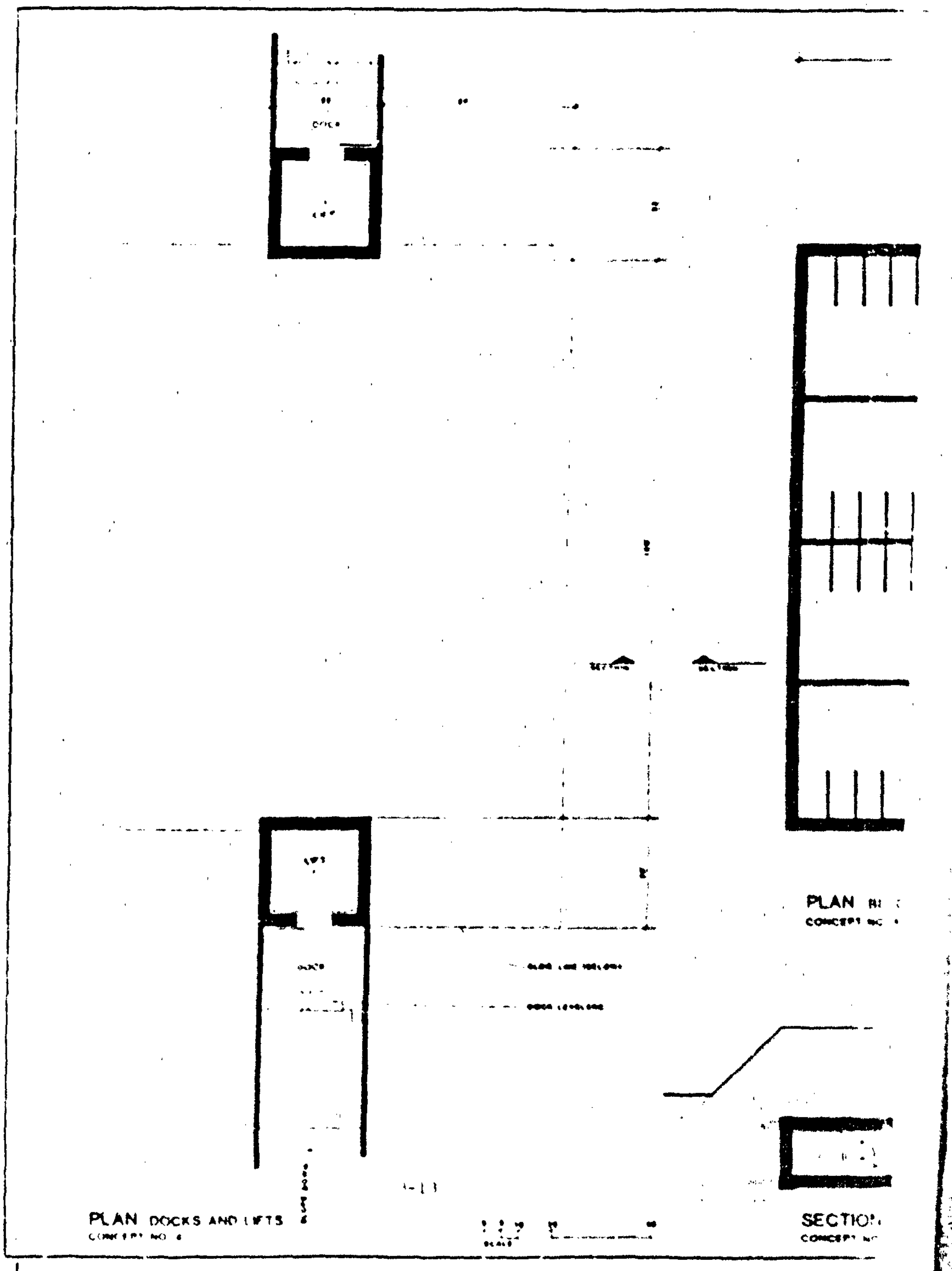
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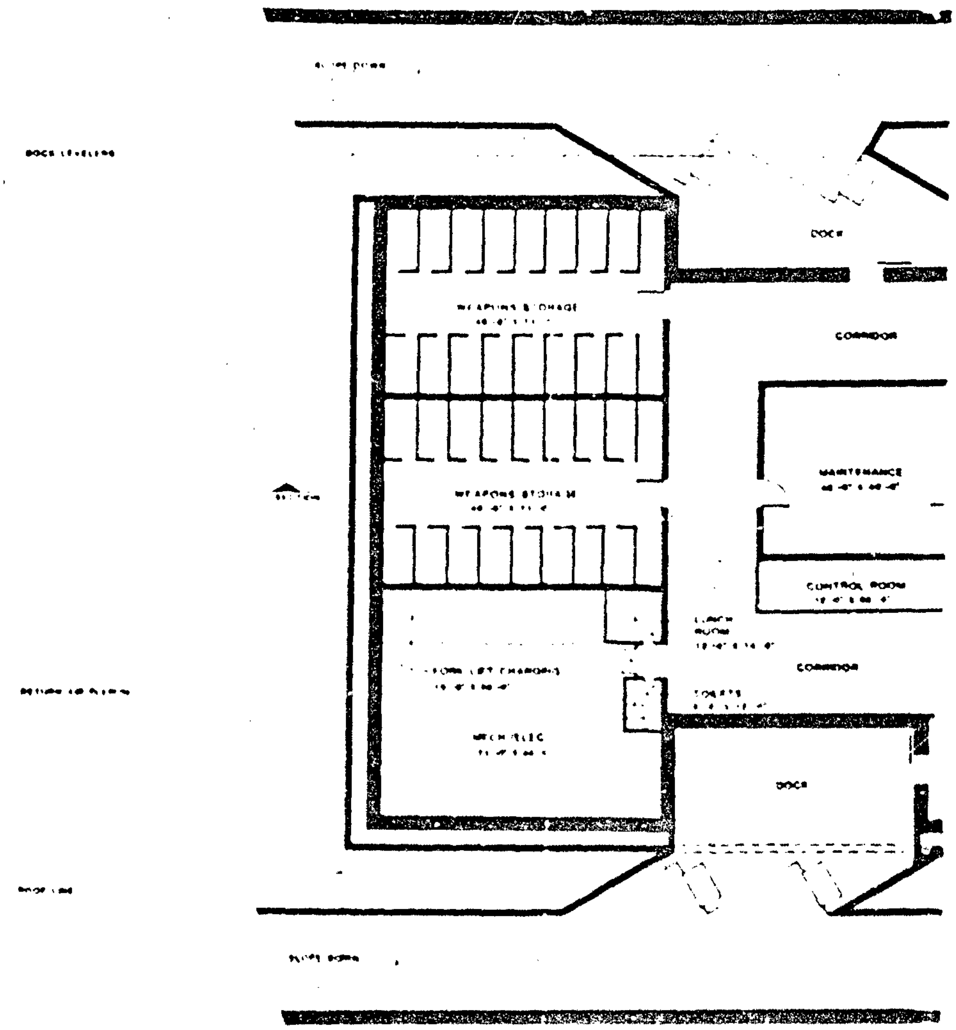
SECTION
PLAN



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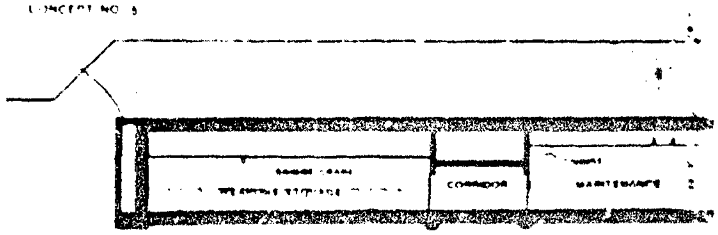

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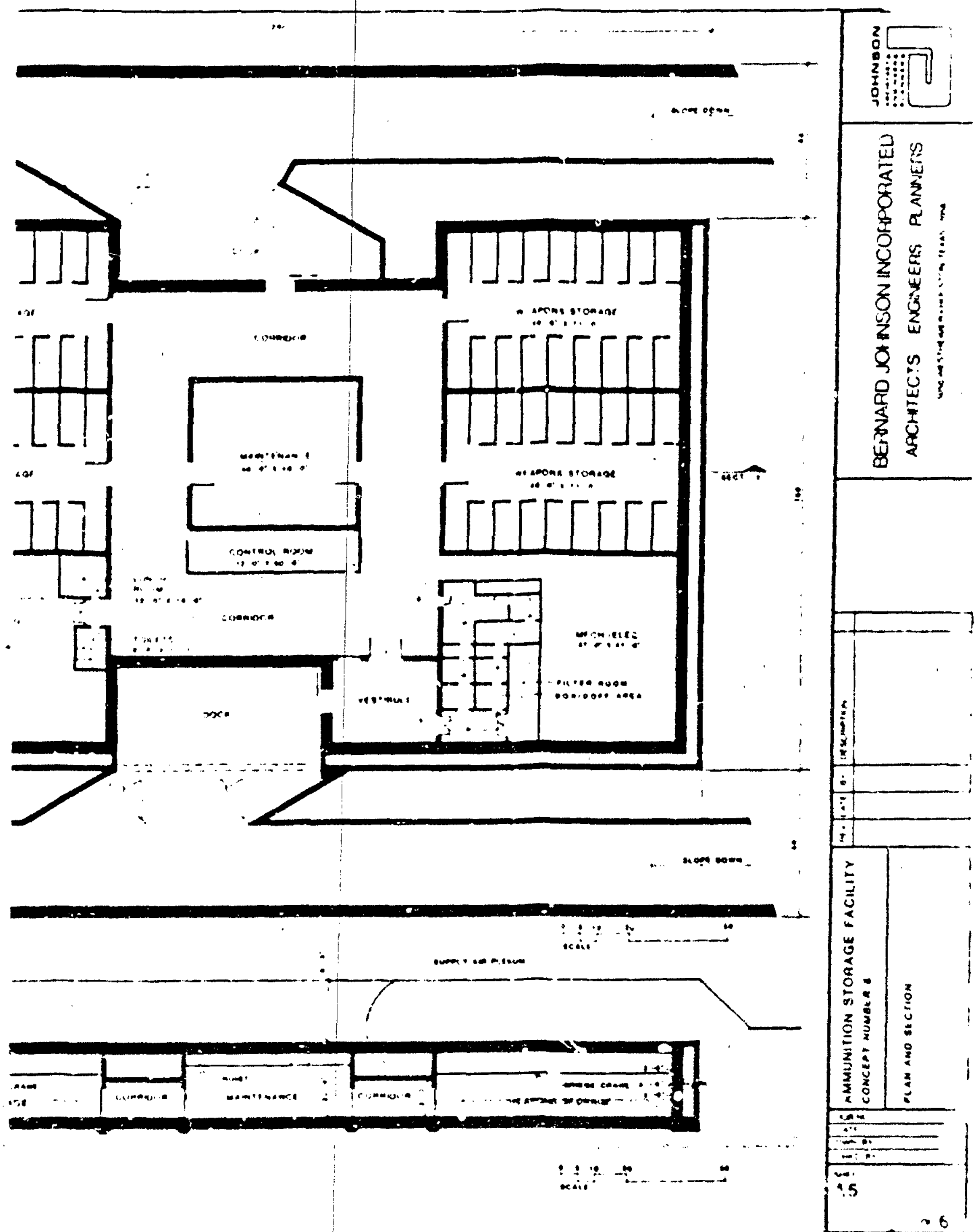

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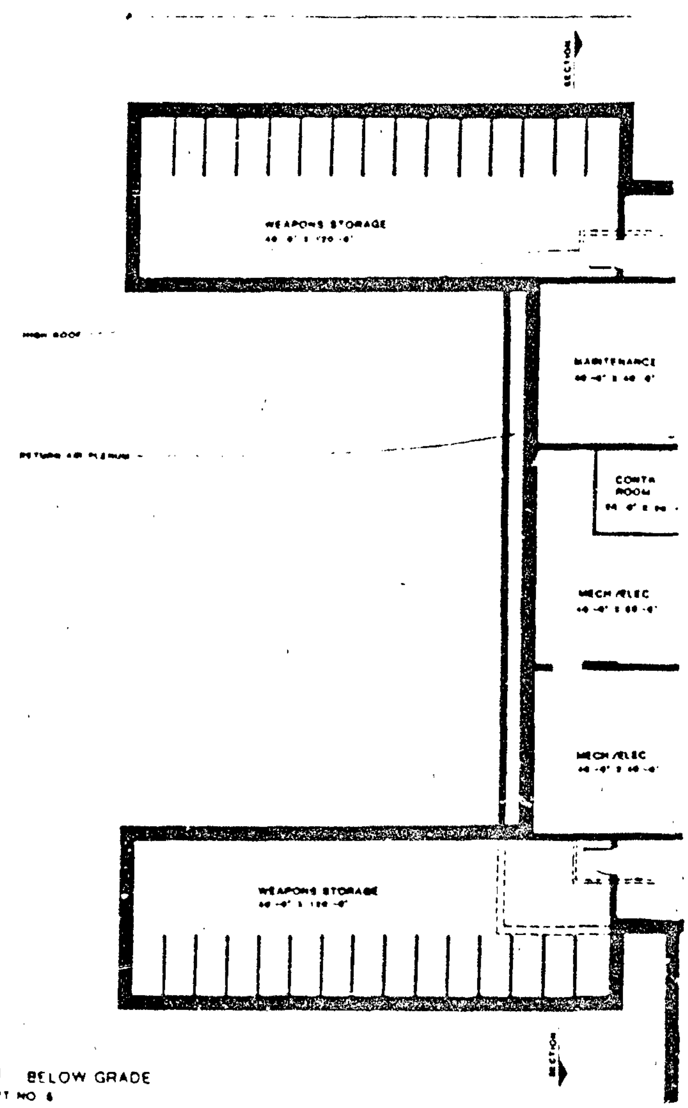
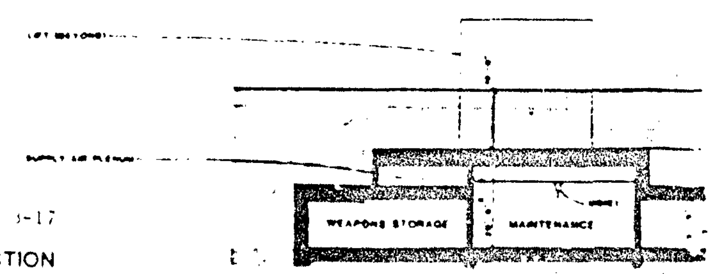
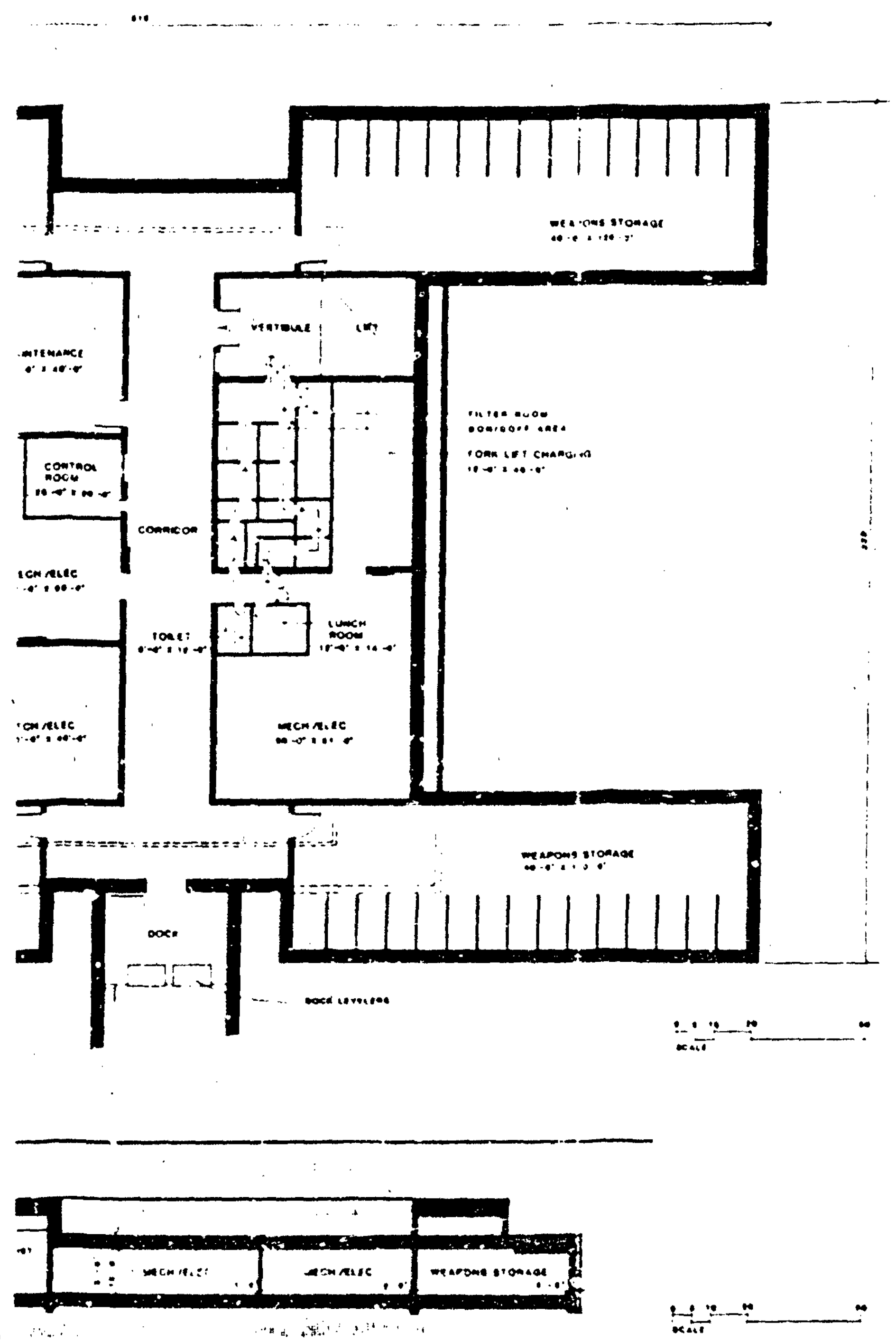
SLOPE DOWN
WEAPONS STORAGE
CORRIDOR
MAINTENANCE
WEAPONS STORAGE
CONTROL ROOM
CORRIDOR
MECH/ELEC
FILTER ROOM
VESTIBULE
DOCK
SLOPE DOWN
SCALE
SUPPLY AIR PLENUM
CORRIDOR
MAINTENANCE
CORRIDOR
BRIDGE CRANE
SCALE
AMMUNITION STORAGE FACILITY
CONCEPT NUMBER 6
PLAN AND SECTION



PLAN BELOW GRADE
CONCEPT NO 6



SECTION
CONCEPT NO 6



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ARCHITECTS · ENGINEERS · PLANNERS

AMMUNITION STORAGE FACILITY

CONCEPT NUMBER 6

PLAN AND SECTION

SHEET A6 of 6

2

SECTION II

ARCHITECTURAL NARRATIVE

PART 1 - GENERAL

The six architectural concepts presented in this description and in the drawings in Section One were developed from criteria supplied by Southwest Research Institute and respond to requirements identified for function, security and safety. Although a preliminary analysis of applicable building, life safety and fire codes was conducted, compliance with these code requirements has been waived by direction from the principal investigator for Southwest Research Institute in favor of more rigid requirements for security and functional capability.

PART 2 - CONCEPTS

2.1 BASIC REQUIREMENTS

A. Each of the six (6) concepts developed included the basic requirements for weapons storage bays or rooms, a weapons maintenance room, a control room, mechanical/electrical room(s), loading dock(s), and air-lock or vestibule, a contamination control (change) area and circulation corridor.

B. Basic material handling requirements for all concepts include a two-ton capacity overhead bridge crane in the weapons maintenance room and a battery powered fork lift truck for general handling and transport of weapons units within the facility. Dock levellers are required at each loading dock position.

2.2 CONCEPT NO. 1

A. Space Requirements: Concept No. 1 consists of a total gross area of 36,357 SF, with a net area of 18,050 SF. Functional areas within the facility are: Weapons Storage Rooms (four at 2,520 SF each); Control Room (500 SF); Toilets (102 SF); Lunch Room (168 SF); Maintenance Area (2,108 SF); Contamination Control Area (1,500 SF); Fork-lift Charging Area (624 SF); Mechanical/Electrical Areas (two at a total of 5,768 SF); Vestibule (625 SF); Corridor (3,525 SF); and two Covered Docking Areas (3,069 SF total).

B. Materials Systems

1. Walls: The structure consists of specially reinforced waterproofed concrete walls, designed to withstand and contain an accidental explosion with no structural damage to the facility. Explosions occurring in

the Weapons Storage Rooms or Maintenance Area will be contained within that respective space.

2. Roof: The roof will be reinforced concrete with an elastic waterproofing membrane and protection board.

3. Floors: Floors in all areas will be hardened, reinforced concrete.

4. Ceilings: Ceilings in all areas will be reinforced concrete.

5. Doors and Windows: A wire-glass glazed window in a hollow-metal frame will be located between the Control Room and Corridor. All Weapons Storage Rooms and the Maintenance Area will have 7' X 9' blast doors. Personnel doors will be 3' X 7' hollow metal doors. Areas requiring forklift access will have sliding metal doors, except at the Contamination Control Area, where swinging metal doors will be used.

   Exterior doors will be sliding metal doors, resistant to blast and forcible entry.

6. Finishes: All interior concrete walls and ceilings shall be painted with alkyd enamel paint and primer.

   All interior concrete floors shall be exposed hardened concrete.

   Metal doors and frames shall be painted with enamel paint over factory primer.

   Industrial machinery, equipment and piping shall be painted with linseed alkyd-resin paint and primer.

2.3 CONCEPT NO. 2

A. Space Requirements: Concept No. 2 consists of a total gross area of 39,200 SF, with a net area of 20,095 SF. Functional areas within the facility are: Weapons Storage Rooms (four at 3,124 SF each); Control Room (500 SF); Toilets (102 SF); Lunch Room (168 SF); Maintenance Area (1,800 SF); Contamination Control Area (1,500 SF); Forklift Charging Area (624 SF); Mechanical/Electrical Rooms (2 at a total of 5,513 SF); Vestibule (624 SF); Corridor (4,038 SF); and two covered Docking Areas (3,007 SF total).

B. Materials Systems

1. Walls: The structure consists of specially reinforced, waterproofed concrete walls, designed to withstand and contain an accidental explosion with no structural damage to the facility. Explosions occurring in the Weapons Storage Rooms or Maintenance Area will be contained within the respective space.

2. Roof: The roof will be reinforced concrete with an elastic waterproofing membrane and protection board.

3. Floors: Floors in all areas will be hardened, reinforced concrete.

4. Ceilings: Ceilings in all areas will be reinforced concrete.

5. Doors and Windows: A wire-glass glazed window in a hollow-metal frame will be located between the Control Room and Corridor. All weapons Storage Rooms and the Maintenance Area will have 7' X 9' blast doors. Personnel doors shall be 3' X 7' hollow metal doors. Areas requiring forklift access shall have sliding metal doors, except at the Contamination Control Area, where swinging metal doors will be used.

   Exterior doors will be sliding metal doors, resistant to blast and forcible entry.

6. Finishes: All interior concrete walls and ceilings shall be painted with alkyd enamel paint and primer.

   All interior concrete floors shall be exposed, hardened concrete.

   Metal doors and frames shall be painted with enamel paint over factory primer.

   Industrial machinery, equipment and piping shall be painted with linseed alkyd-resin paint and primer.

7. Handling Equipment: Two-ton bridge cranes are also required in each of weapons storage rooms.

2.4 CONCEPT NO. 3

A. Space Requirements: Concept No. 3 consists of a total gross area of 43,775 SF, with a net area of 17,538 SF. Functional areas within the facility are: Weapons Storage Rooms (four at 2,520 SF each); Control Room (500 SF); Toilets (102 SF); Lunch Room (168 SF); Maintenance Area

(2,520 SF); Contamination Control Area (1,500 SF); Forklift Charging Area (600 SF); Mechanical/Electrical Areas (three at a total of 4,710 SF); two Vestibules (2,000 SF total); Corridor (5,500 SF); Lifts (two at 725 SF each); and two Covered Docking Areas (2,170 SF total).

B. Materials Systems

1. Walls: The structure consists of specially reinforced, waterproofed concrete walls, designed to withstand and contain an accidental explosion with no structural damage to the facility. Explosions occurring in the Weapons Storage Rooms or Maintenace Area will be contained within that respective space.

2. Roof: The roof will be reinforced concrete with an elastic waterproofing membrane and protection board.

3. Floors: Floors in all areas will be hardened, reinforced concrete.

4. Ceilings: Ceilings in all areas will be reinforced concrete.

5. Doors and Windows: A wire-glass glazed window in a hollow-metal frame will be located between the Control Room and Corridor. All Weapons Storage Rooms and the Maintenance Area will have 7' X 9' blast doors. Personnel doors shall be 3' X 7' hollow metal doors. Areas requiring forklift access shall have sliding metal doors, except at the Contamination Control Area, where swinging metal doors will be used.

   Exterior doors will be sliding metal doors, resistant to blast and forcible entry.

6. Finishes: All interior concrete walls and ceilings shall be painted with alkyd enamel paint and primer.

   All interior concrete floors shall be exposed, hardened concrete.

   Metal doors and frames shall be painted with enamel paint over factory primer.

   Industrial machinery, equipment and piping shall be painted with linseed alkyd-resin paint and primer.

2.5 CONCEPT NO. 4

A. Space Requirements: Concept No. 4 consists of a total gross area of 48,100 SF, with a net area of 27,436 SF.

Functional areas within the facility are: Weapons Storage Rooms (four at 3,266 SF each); Control Room (600 SF); Toilets (102 SF); Lunch Room (168 SF); Maintenance Area (2,208 SF); Contamination Control Area (1,500 SF); Forklift Charging Area (728 SF); Mechanical/Electrical Areas (two at a total of 4,661 SF); Vestibule (750 SF); Corridor (8,150 SF); and two Covered Docking Areas (9,170 SF total). Bridge cranes will be required in the four Weapons Storage Rooms and a 2-ton hoist shall be required in the Maintenance Area.

B. Materials Systems

1. Walls: The structure consists of specially reinforced, waterproofed concrete walls, designed to withstand and contain an accidental explosion with no structural damage to the facility. Explosions occurring in the Weapons Storage Rooms or Maintenance Area will be contained within that respective space.

2. Roof: The roof will be reinforced concrete with an elastic waterproofing membrane and protection board.

3. Floors: Floors in all areas will be hardened, reinforced concrete.

4. Ceilings: Ceilings in all areas will be reinforced concrete.

5. Doors and Windows: Wire-glass glazed windows in a hollow metal frame will be located between the Control Room and Corridor. All Weapons Storage Rooms and the Maintenance Area will have 7' X 9' blast doors. Personnel doors shall be 3' X 7' hollow metal doors. Areas requiring forklift access shall be sliding metal doors, except at the Contamination Control Area, where swinging metal doors shall be used.

   Exterior doors will be sliding metal doors, resistant to blast and forcible entry.

6. Finishes: All interior concrete walls and ceilings shall be painted with alkyd enamel paint and primer.

   All interior concrete floors shall be exposed, hardened concrete.

   Metal doors and frames shall be painted with enamel paint over factory primer.

   Industrial machinery, equipment and piping shall be painted with linseed alkyd-resin paint and primer.

2.6 CONCEPT NO. 5

A. Space Requirements: Concept No. 5 consists of a total gross area of 44,020 SF, with a net area of 25,814 SF. Functional areas within the facility are: Weapons Storage Rooms (four at 4,800 SF each); Control Room (500 SF); Toilets (102 SF); Lunch Room (168 SF); Maintenance Area (1,998 SF); Contamination Control Area (1,500 SF); Fork-lift Charging Area (648 SF); Mechanical/Electrical Areas (three at a total of 5,060 SF); Vestibule (500 SF); Corridor (3,978 SF); two Covered Docking Areas (1,800 SF total); and two lifts (625 SF each).

B. Materials Systems

1. Walls: The structure consists of specially reinforced, waterproofed concrete walls, designed to withstand and contain an accidental explosion with no structural damage to the facility. Explosions occurring in the Weapons Storage Rooms or Maintenance Area will be contained within that respective space.

2. Roof: The roof will be reinforced concrete with an elastic waterproofing membrane and protection board.

2. Floors: Floors in all areas will be hardened, reinforced concrete.

4. Ceilings: Ceilings in all areas will be reinforced concrete.

5. Doors and Windows: A wire-glass glazed window in a hollow-metal frame will be located between the Control Room and Corridor. All Weapons Storage Rooms and the Maintenance Area will have 7' X 9' blast doors. Personnel doors shall be 3' X 7' hollow metal doors. Areas requiring forklift access shall have sliding metal doors, except at the Contamination Control Area, where swinging metal doors shall be used.

   Exterior doors shall be sliding metal doors, resistant to blast and forcible entry.

6. Finishes: All interior concrete walls and ceilings shall be painted with alkyd enamel paint and primer.

   All interior concrete floors shall be exposed, hardened concrete.

   Metal doors and frames shall be painted with enamel paint over factory primer.

Industrial machinery, equipment and piping shall be painted with linseed alkyd-resin paint and primer.

2.7 CONCEPT NO. 6

A. Space Requirements: Concept No. 6 consists of a total gross area of 49,137 SF, with a net area of 25,404 SF. Functional areas within the facility are: Weapons Storage Rooms (four at 4,800 SF each); Control Room (500 SF); Toilets (102 SF); Lunch Room (168 SF); Maintenance Area (1,600 SF); Contamination Control Area (1,500 SF); Forklift Charging Area (576 SF); Mechanical/Electrical Areas (three at a total of 3,763 SF); Vestibule (650 SF); Corridor (6,221 SF); Lift (615 SF); and two Covered Docking Areas (1,860 SF total).

B. Materials Systems

1. Walls: The structure consists of specially reinforced, waterproofed concrete walls, designed to withstand and contain an accidental explosion with no structural damage to the facility. Explosions occurring in the Weapons Storage Rooms or Maintenance Area will be contained within that respective space.

2. Roof: The roof will be reinforced concrete with an elastic waterproofing membrane and protection board.

3. Floors: Floors in all areas will be hardened, reinforced concrete.

4. Ceilings: Ceilings in all areas will be reinforced concrete.

5. Doors and Windows: A wire-glass glazed window in a hollow-metal frame will be located between the Control Room and Corridor. All Weapons Storage Rooms and the Maintenance Area will have 7' X 9' blast doors. Personnel doors shall be 3' X 7' hollow metal doors. Areas requiring forklift access shall have sliding metal doors, except at the Contamination Control Area, where swinging metal doors shall be used.

   Exterior doors shall be sliding metal doors, resistant to blast and forcible entry.

6. Finishes: All interior concrete walls and ceilings shall be painted with alkyd enamel paint and primer.

   All interior concrete floors shall be exposed, hardened concrete.

Metal doors and frames shall be painted with enamel paint over factory primer.

Industrial machinery, equipment and piping shall be painted with linseed alkyd-resin paint and primer.

STRUCTURAL NARRATIVE

PART 1 - GENERAL

1.1 BASIC CHARACTERISTICS

Of the six concepts presented, there are four variations in location of the structures relative to the ground surface, as follows:

A. Concepts No. 1 and No. 2 are single story buildings with the finish floor located approximately at grade level. The perimeter walls are surrounded by an earthen berm covered with concrete. A shallow concrete covered earth fill covers the building roof.

B. Concept No. 3 is a two story building with the upper floor level approximately at grade and the basement level fully below grade (partially buried structure). Perimeter walls and roof are covered in the same manner as concepts No. 1 and No. 2.

C. Concepts No. 4 and No. 5 are single story buildings with the roof level approximately at grade and covered by a deep earthen berm.

D. Concept No. 6 is a single story building with the roof level located beneath deep earth fill.

1.2 SIMILAR STRUCTURAL SYSTEMS

A. The above concepts have construction similarities to other structures not uncommon in the Houston-Galveston area. Below grade sanitary structures, below grade parking garages, basement levels of multi-story buildings and, of course, the abandoned Coast Artillery gun emplacement at Fort Crockett in Galveston are examples of structures with similar concepts.

PART 2 - SUPERSTRUCTURE

2.1 BASIC REQUIREMENTS

A. Because the buildings are designed to prevent forced entry, resist shock loading either from external sources or internal accidents and are to be either earth covered or buried, the construction will be of reinforced concrete.

2.2 ROOFS

A. Roofs will be of heavy reinforced concrete construction designed to support the earth cover and to resist the

shock loading. It is anticipated that the roof thickness will range from 3 ft. - 6 in. to 6 ft. depending on the particular span; the roof slab will be reinforced with two layers of steel bars in each direction, and in addition, be reinforced with vertical stirrups for the shear induced by the shock loading.

2.3 WALLS

A. Perimeter wall will be comprised of an interior wall approximately 4 ft. thick, a 3 ft. plenum space and a 2 ft. exterior wall. The exception is concept No. 4 in which both the supply and return plenum space are located above the ceiling of the corridor and part of the weapons storage bays.

B. The portions of interior perimeter wall at the weapons storage bays and maintenance bays will be of laced reinforced concrete construction; these walls could be subjected to the overpressures from an H. E. accident. The remaining portions of the perimeter wall will not require lacing.

C. The exterior perimeter wall and the dock and ramp walls will be of conventional (not laced) reinforced concrete construction.

D. The interior load bearing walls at the weapons storage and maintenance bays will be of laced reinforced concrete construction; other interior walls will be conventional (not laced) reinforced concrete construction.

2.4 FLOORS

A. Concept No. 3, which is two story, will have a laced reinforced concrete floor at the upper level; this floor is the ceiling of the weapons storage bays.

PART 3 - FOUNDATIONS

3.1 GEOTECHNICAL ASSUMPTIONS

A. Specific recommendations regarding foundation design would come as a result of a geotechnical investigation based on sampling and testing of soil materials at the site or sites selected.

B. Surface and subsurface materials in the Houston-Galveston area are predominately clay although the material in the immediate vicinity of the coast becomes predominately sandy. The strength of these materials varies throughout the area; for example, bearing capacities for footings founded at a ten foot depth can range from 2,500 to 5,000 pounds per square foot or more. If the surface

materials are very poor, they can be stabilized with hydrated lime in order to provide a better subgrade for slabs at grade and pavements. Subsurface materials can be improved with lime injection.

3.2 CONCEPT NO. 1 AND NO. 2 (AT GRADE STRUCTURES)

A. Floor Slab: Since the perimeter walls and many of the interior walls are subject to shock loading, a heavy mat type reinforced concrete floor slab will be used to transfer the loads and stresses from these walls. The mat will be approximately equal in thickness to the perimeter wall and will be reinforced with two layers of reinforcing steel in each direction.

B. Mat type floor slabs in the coastal vicinities may require piling if the sandy materials do not provide adequate support for a slab on grade.

C. The slabs at the loading dock and ramps will be 6 to 8 in. thick slab on grade.

D. Both perimeter walls and interior walls are subject to extremely high axial loading imposed by the roof and the weight of the wall itself. These loads will be resisted by piling, either augered or driven, depending on the specific geotechnical recommendations.

3.3 CONCEPT NO. 3 THROUGH 6 (PARTIALLY OR FULLY BURIED STRUCTURES)

A. Floor Slab (basement floor only for Concept No. 3): In addition to transferring shock loading (and backfill loading at the perimeter) from the walls, the mat slab also resists hydrostatic uplift pressures. These uplift forces are counteracted by the dead weight of the structure plus the fill.

B. The vertical forces acting through walls will be distributed to the rigid mat slab through bending action at sites where the subsurface material has adequate bearing capacity. At sites where the subsurface material is weak, piling will be used beneath the walls as required to aid the mat in resisting the vertical loads. At perimeter walls, the skin friction of the adjacent soil will also aid in resisting the vertical loads.

3.4 BUCYANCY

A. The concepts presented have adequate weight to resist the hydrostatic uplift forces with an appropriate safety factor. A final buoyancy check will be based on information from a geotechnical investigation and the final design.

3.5 WATERPROOFING

A. The structures will have exterior waterproofing of base slabs, walls and roofs to prevent moisture from permeating the concrete.

HEATING, VENTILATING AND AIR CONDITIONING NARRATIVE

PART 1 - GENERAL

1.1 BASIC CRITERIA

A. ASHRAE Manuals: "Equipment", "Systems", "Fundamentals" and "Applications".

B. NFPA 90A.

C. Standard Building Code.

1.2 DESIGN CONDITIONS

A. Outdoor Temperatures:

Summer:	95°FDB, 80°FWB
Winter:	28°FDB

B. Indoor Temperatures:

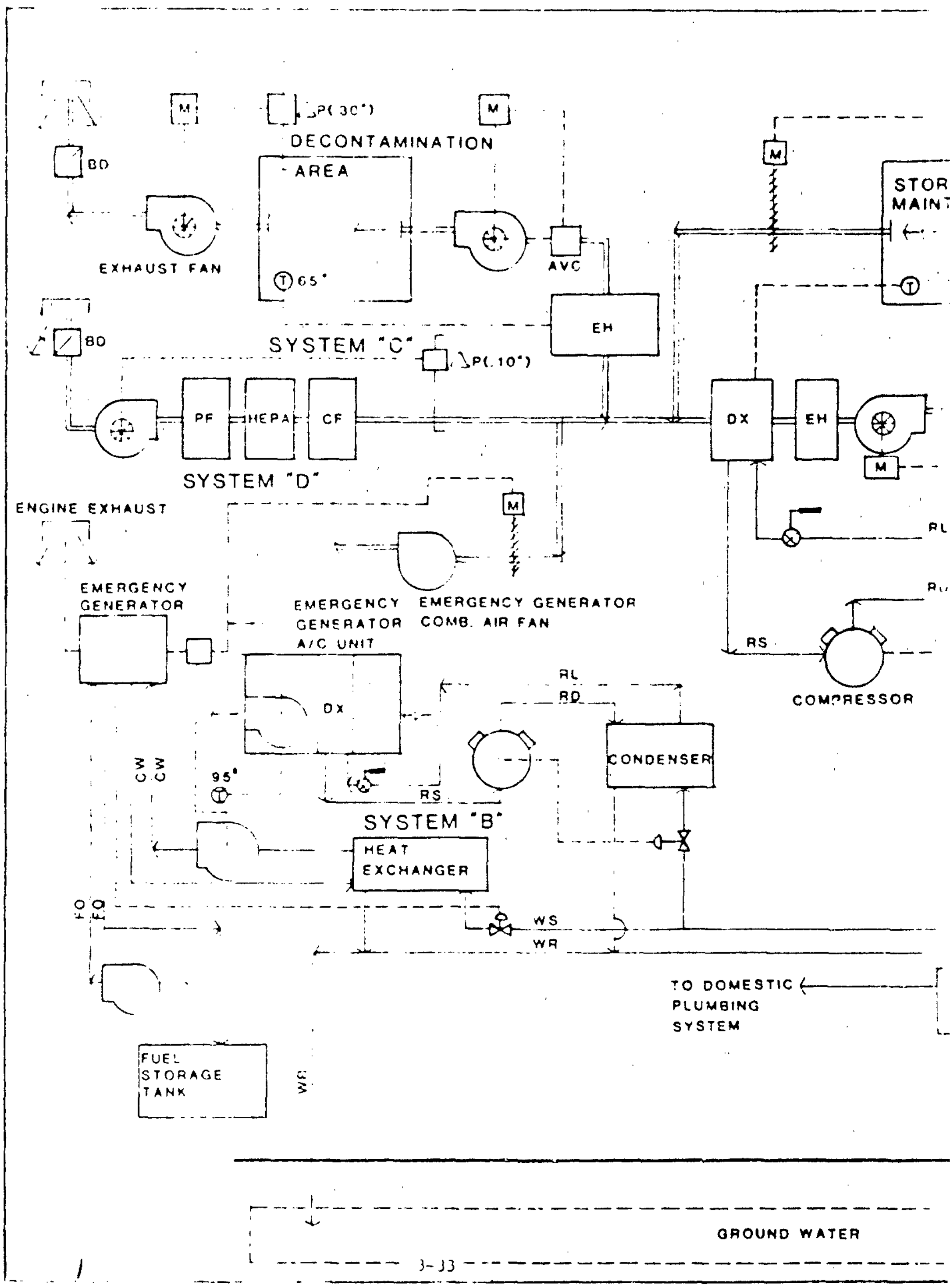
	Cooling	Heating
Weapons Storage	80°FDB, 60% R.H.(max.)	65°FDB
Corridor, Control Room, Maintenance, Toilets, Lunch Room	75°FDB, 60% R.H.(max.)	72°FDB
Mechanical and Electrical Equipment Rooms	85°FDB	65°
Contamination Control	Ventilation	65°FDB

C. Pressure Relationships (Related to Ambient Pressure)

Corridor	+.30" w.g.
Dress Room	+.30" w.g.
Shower	+.25"w g.
Undress Room	+.25" w.g.
Air Locks	+.20" w.g.
Vapor Hazard	+.15" w.g.
Liquid Hazard	+.10" w.g.

1.3 HVAC SYSTEM SCHEMATIC

A. The following page shows a schematic diagram of a heating ventilating and air conditioning system for the facility.



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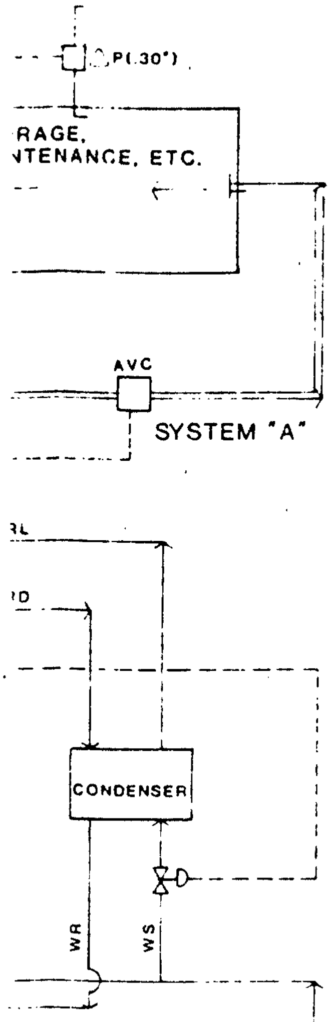
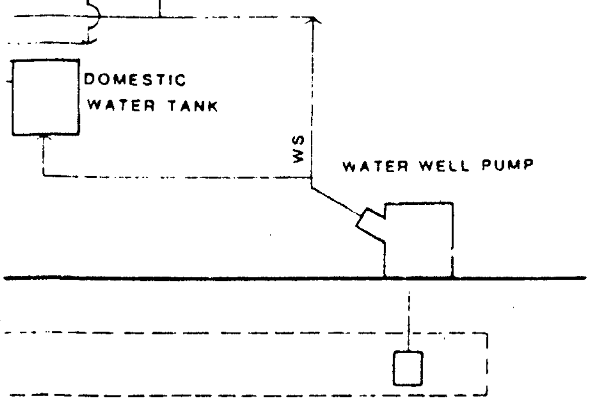


LEGEND

AVC	AIR VOLUME CONTROL
BD	BLAST DAMPER
CF	CHARCOAL FILTER
CW	GENERATOR COOLING WATER
DX	REFRIGERATION COOLING COIL
EH	ELECTRIC DUCT HEATER
FO	FUEL OIL
HEPA	ABSOLUTE FILTER
M	DAMPER MOTOR
PF	PRE-FILTER
RD	REFRIGERATION HOT GAS
RL	REFRIGERATION LIQUID
RS	REFRIGERATION SUCTION GAS
T	THERMOSTAT
WR	WELL RETURN WATER
WS	WELL SUPPLY WATER
ΔP	DIFFERENTIAL PRESSURE CONTROL
═══	AIR DUCTS
- - -	CONTROL CIRCUIT
······	PIPING



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DWN BY:

CHKD BY

APPROVED:

AMMUNITION STORAGE FACILITY
CONCEPT NUMBERS 1-6

HVAC SYSTEM SCHEMATIC

JOHNSON

B. The diagram shows general system arrangement but not necessarily the final design solution.

PART 2 - AIR CONDITIONING AND VENTILATION SYSTEMS

2.1 SYSTEM A (AIR CONDITIONING)

A. System shall serve weapons bays, corridor, maintenance, control room, toilets, lunch room and mechanical and electrical equipment rooms. Air handling and refrigeration equipment shall be located in the mechanical equipment room.

B. System shall be recirculating air type with sufficient outside air to make-up exhaust from toilet and to provide the required positive pressure inside the building.

C. The plenum above the corridor is enclosed on all four sides by reinforced concrete construction. This area shall be used as supply air duct to convey air to the four weapons bays. A reinforced concrete plenum around the outside building perimeter shall be used to return air from the weapons bays.

D. Air shall be supplied to each bay through a HEPA filter mounted securely in the wall and open to the ceiling supply air plenum. Air shall be returned from each bay through a HEPA filter mounted securely in the wall adjacent to the return air plenum. The purpose of the HEPA filters is to prevent contaminated air from backing up from one weapons bay to the others in the event of an explosion.

E. Necessary dampers and controls shall be provided to maintain the indoor building pressure at the required positive pressure in relation to the outdoor pressure.

F. Condenser cooling water for the refrigeration equipment shall be supplied from the injection water well system located in the mechanical equipment room.

2.2 SYSTEM B (AIR CONDITIONING)

A. System shall be designed to remove the heat rejected to the mechanical room by the emergency generator. Air handling and refrigeration equipment shall be located in the mechanical room with the emergency generator.

B. System shall be the 100% recirculating air type with no outside air connections.

C. System shall be interlocked with the emergency generator so that it operates only when the emergency generator is in operation.

D. A combustion air fan shall be provided and shall be interlocked to run when the generator is in operation. Fan shall supply prefiltered and unconditioned outside air to the mechanical room.

D. Condenser cooling water for the refrigeration equipment shall be supplied from the injection water well system.

2.3 SYSTEM C (CONTAMINATION CONTROL AREA VENTILATION)

A. A ventilation system shall be provided for the contamination control area.

B. System shall ventilate the area with 100% prefiltered outside air.

C. System shall be equipped with supply fan exhaust fan, dampers and automatic controls required to maintain the required space pressure relationships in the various spaces.

D. Heating shall be included to maintain the required space temperature.

E. Blast dampers shall be provided in the exhaust air duct which discharges air from the building. Discharge opening shall be designed to prevent entrance by intruders and to prevent explosives from being placed into the opening.

2.4 SYSTEM D (OUSIDE AIR FILTRATION)

A. Provide an outside air filtration system to supply prefiltered outside air for the contamination control area ventilation system, main building air conditioning system and emergency generator combustion air fan.

B. The intake duct extending out of the building shall be equipped with a blast damper. Intake opening shall be designed to prevent entrance by intruders and to prevent explosives from being placed into the opening.

C. System shall include an outside air fan which intakes outside air and discharges the air through a roughing filter, HEPA filter and finally through a charcoal filter.

D. System shall be equipped with necessary controls to automatically control the volume of air delivered by the supply fan to compensate for increased fan static due to dust loading of the filters.

PART 3 - DESIGN CRITERIA RATIONAL

2.1 AIR CONDITIONING AND VENTILATION SYSTEMS

A. Comfort air conditioning is specified for the control

room, maintenance, corridor, lunch room and toilets to provide a comfortable working environment for the operating personnel. Weapons bays and mechanical/electrical rooms are also air conditioned.

B. Consideration was given to ventilating the weapons storage bays and mechanical/electrical rooms with outside air as opposed to air conditioning. A ventilation system would require relatively large volumes of air be taken in and exhausted from the building. This would require much larger intake and exhaust openings and also a much larger outside air filtration system. Large intake and exhaust openings would be more difficult to secure against intrusion and blast. Air conditioning of these areas was selected as the most feasible alternative.

2.2 EMERGENCY GENERATOR AND REFRIGERATION EQUIPMENT HEAT REJECTION SYSTEM

A. Consideration was given to the use of a remote air cooled radiator for the emergency generator and remote air cooled condensers for the refrigeration equipment. The remote units would be located outdoors and subject to damage by intruders. This was considered unacceptable.

B. Consideration was given to the same type system except the emergency generator radiator and air cooled condensers would be located within the blast resistant structure. The air cooled radiator and air cooled condensers require large volumes of air to carry away heat rejected from the equipment. This would necessitate large openings for intake air and exhaust air. Large openings would be difficult to secure against intrusion and blast. This arrangement was rejected as unacceptable.

C. The use of a cooling tower was also considered. Pumps would circulate cooling tower water between the tower and the emergency generator and refrigeration equipment heat. This type arrangement was considered unacceptable for the same reasons as the air cooled heat exchanger concept was rejected.

D. An injection type water well system was selected as the most desirable means of removing heat rejected from the emergency generator and refrigeration equipment. A well pump would circulate water through the equipment heat exhangers and then return the underground water system. The well would also supply the domestic water plumbing system. The well equipment could be located within the blast resistant structure and inaccessible to intruders.

PLUMBING AND FIRE PROTECTION NARRATIVE

PART 1 - GENERAL

1.1 BASIC CRITERIA

A. Standard Building Code.

B. NFPA 10

C. NFPA 13

1.2 BASIS OF DESIGN

A. Sanitary waste and vent system shall be designed on the "Per Fixture Unit" basis.

B. Domestic cold water system shall be designed on the "Per Fixture Unit" basis.

C. Domestic hot water system shall be designed on the "Per Fixture Unit" basis.

D. Portable fire extinguishers shall comply with the requirements of NFPA-10.

E. Fire sprinkler systems shall be designed in accordance with NFPA-13.

1.3 OUTSIDE UTILITIES

A. Fire water and sanitary sewer lines shall terminate five feet outside of the building line.

B. Extending the utilities beyond the five foot line is not included in the scope of this report.

PART 2 - SYSTEMS DESCRIPTION

2.1 DOMESTIC WATER SYSTEMS

A. Domestic cold water shall be piped to all plumbing fixtures including lavatories, water closets, urinals, service sinks and hose outlets.

B. Hot water shall be supplied to lavatories and service sinks. Hot water shall be supplied by electric water heaters.

2.2 WATER WELL SYSTEM

A. An injection type water well shall be provided with sufficient capacity to supply the domestic water demand and cooling water requirements of the emergency generator and air conditioning system refrigeration equipment.

B. Cooling water for the emergency generator and refrigeration compressors shall be pumped through heat exchangers on the equipment and then returned to the ground.

2.3 FIRE SPRINKLER SYSTEM

A. A wet pipe fire sprinkler system shall be provided for all areas in the facility. The hazard classification for the various occupancies will be determined during the design phase. Water supply shall be from the main base water system.

B. The need for high volume deluge system in the weapons storage bays may be considered in the design phase.

2.4 FIRE EXTINGUISHERS

A. Hand held portable fire extinguishers shall be provided in the main service corridor and in mechanical and electrical equipment rooms.

B. Extinguishers shall be surface mounted on wall brackets.

2.5 SANITARY WASTE SYSTEM

A. A complete sanitary waste and vent system shall be extended to all plumbing fixtures, equipment and flow drains and connected to the sanitary sewer main.

B. Provide a duplex sewerage ejector with sufficient lift to pump sewerage into the gravity sewer.

C. All vent stacks shall be designed to be bomb proof.

2.6 COMPRESSED AIR SYSTEM

A. A compressed air piping system shall be provided to serve the facility including pneumatic door operators, pneumatic tool air outlets and air operated hoists.

B. A duplex air compressor shall be provided to supply compressed air to the system.

ELECTRICAL NARRATIVE

PART 1 - BASIC REQUIREMENTS

1.1 GENERAL

A. Electrical work shall conform with the requirements of the latest edition of the National Electrical Code, Life Safety Code, and local codes and ordinances. In case of conflict, local codes and ordinances shall govern.

B. Materials and equipment shall conform to and be in accordance with the latest applicable standards of National Electrical Manufacturers Association (NEMA), American National Standards Institute (ANSI), and Insulated Cable Engineers Association (ICEA) where standards have been established for the specific items of materials and equipment. Where inspection categories have been established by Underwriters Laboratories, materials and equipment shall bear their label.

C. An EMR clean environment shall be provided in accordance with DARCOM 385-100, 6-14.

PART 2 - SERVICE AND DISTRIBUTION

2.1 MUNITIONS STORAGE

A. A new substation will be provided in the building. Equipment shall consist of a power center 300 KVA dry type transformer and bolted type air circuit breaker substation for secondary distribution. System voltage shall be 480 volts, 3 phase, 4 wire secondary.

B. The transformer will be supplied from a load break switch located in the substation.

C. The primary service feed from the utility to the substation will be installed in concrete encased conduit. Cable will be fire proofed whenever exposed.

D. The transformer will be sized to provide 100% spare capacity.

E. The substation will supply power to the parking lot lighting.

F. The estimated total connected load for the substation will be 157.5 KVA.

2.2 SECONDARY DISTRIBUTION

A. Secondary distribution within buildings will be at 480

volts. Generally, HVAC systems will be served at 480 volts and the fluorescent lighting system at 120 or 277 volts.

B. Dry type transformers will be installed to provide 208/120 volt service for lighting convenience receptacles and miscellaneous equipment.

C. Secondary distribution, 480/277 and 208/120 volt systems within buildings, will be wire in conduit and circuit breaker panelboards.

D. Equipment used to distribute power to loads shall be 480 volt, 3 phase, 3 wire motor control centers, 480 volt, 3 phase, 4 wire power panels and 208/120 volt, 3 phase, 4 wire lighting and receptacle panels. All motor control centers power panels, dry type transformers and lighting panels are to be located in separate rooms for electrical equipment.

E. Ammeters, voltmeters and KWH-demand meters are to be provided in addition to utility metering.

PART 3 - LIGHTING SYSTEMS

3.1 GENERAL

A. Lighting systems will conform to engineering practice using standards from the Illuminating Engineers Socieity handbook as guidelines.

B. Systems will utilize energy efficient light sources. Lamp life and ease of maintenance will be given effective consideration.

C. Roads, parking, and walks will be illuminated to approximately 0.5 footcandle on roads and 2.0 footcandle on parking and walk areas using high pressure sodium as a light source.

D. Control room will be illuminated to approximately 75 maximum footcandles using 2' x 4' fluorescent fixtures. Fixtures will be switched locally providing a multiple level of lighting. Generally, three lamp fixtures will be used with center lamp and two outside lamps switched separately.

E. Maintenance will be illuminated to approximately 90 footcandles using fluorescent fixtures, switched locally. Multi-level lighting will be provided.

F. Warehouse areas will be illuminated to approximately 30 footcandles using Class I Group D, Class II Group G, Division 2 light source fixtures.

G. General and miscellaneous areas will be considered on an individual basis. Special attention and treatment will be given to all areas.

H. Emergency lighting will be provided to insure safe egress in case of power failure or under other emergency conditions.

PART 4 - MAINTENANCE AND CONTROL

4.1 GENERAL

A. Electrical services and outlets will be provided to service maintenance equipment as required.

B. An emergency generator will be provided to service selected areas and control equipment in the event of power failure or other emergency. Equip with diesel fuel day tank, underground storage tank, heat exchanger and engine exhaust sytems.

C. All systems and equipment will be provided with grounding conductors.

PART 5 - AUXILIARY SYSTEMS

5.1 GENERAL

A. Auxiliary systems will be provided complete for the following:
1. Fire alarm system.
2. Closed circuit T. V. surveilance system at control room.
3. A low level distributed sound system, fully equalized will be provided for the building.
4. Computer terminal system will be provided.
5. Security monitoring will be provided through door monitors, sound detectors, motion detectors as required.
6. Individual systems for sensing environmentally hazardous chemicals.
7. Safety monitoring of storage rooms will be provided with pressure monitors set for 5 psi.

B. An empty conduit and pull box system only will be provided for telephone system.

C. Auxiliary systems will be connected to the emergency generator system through a uninterruptable power supply.

PART 6 - LIGHTING PROTECTION AND STATIC GROUNDING

6.1 GENERAL

A. Lighting protection system in accordancw with DARCOM 385-100 and NFPA 78 will be provided.

B. Static grounding system in accordance with DARCOM 385-100 and NFPA 77 will be provided.

SECTION III

Item	Description	Unit Cost	Concept 1 Quantity	Concept 1 Cost	Concept 2 Quantity	Concept 2 Cost
1	General Conditions	7 *		$ 651,600		$ 738,500
2	Building Earthwork					
	A. Excavation	$5.60/ CY	18,900 CY	105,900	29,160 CY	163,300
	B. Fill & Subgrade Prep.	2.87/ CY	20,600 CY	59,100	20,600 CY	59,100
3	Concrete Work					
	A. Concrete	63.63 CY	22,630 CY	1,440,000	27,460 CY	1,747,300
	B. Forms	1.75 SF	286,124 SF	500,000	346,514 CY	606,400
	C. Reinforcing Steel	1,262/ Ton	2,554 Tons	3,223,100	3,097 Tons	3,908,700
	D. Pilings	1,000/ Ea.	400/ Ea.	400,300	483 Ea.	482,700
4	Masonry					
	A. Framing	1,250 Ton	4 Tons	5,000	7.9 Tons	9,900
	B. Railing, Etc.	10 LF	50 LF	500	50 LF	500
6	Wood & Plastics					
7	Thermal & Moisture Prot.	8.10 SF	36,400 SF	295,000	39,200 SF	317,500
8	Doors & Windows					
	A. Blast Doors	138,600/ Ea.	5 Ea.	692,000	5 Ea.	693,000
	B. Exterior Door	8,000 Ea.	2 Ea.	16,000	2 Ea.	16,000
	C. Special Int. Doors	2,005 Ea.	19 Ea.	38,100	20 Ea.	40,100
	D. Hollow Metal Doors	400 Ea.	3 Ea.	1,200	3 Ea.	1,200
	E. Windows	12/ SF	33 SF	400	33 SF	400
	F. Hardware	5,000 Lot	1 Lot	5,000	1 Lot	5,000
9	Finishes	3.45 SF	36,400 SF	140,000	39,200 SF	151,200
10	Specialties	12,000/ Lot	1 Lot	12,000	1 Lot	12,000
11	Equipment					
	A. Casework	175 LF	126 LF	22,100	126 LF	22,100
	B. Dock Levelers	3,700/ Ea	4 Ea.	14,800	4 Ea.	14,800
12	Furnishings					
13	Special Construction					
14	Conveying Systems					
	A. Hoists, Pneumatic	4,500/ Ea.	1 Ea.	4,500	1 Ea.	4,500
	B. Lifts, Hydraulic	40,000 Ea.	-	-	-	-
	C. Bridge Crane	5,000/ Ea.		-	1 Ea.	5,000
15	Mechanical					
	A. Heat., Vent. & A. C. Sys.					
	1. Direct Expansion Sys.	3,000/ Ton	36.8 Tons	110,400	37.6 Tons	112,800
	2. Free Blow A. C. Sys.	800/ Ton	13.8 Tons	11,000	14.1 Tons	11,300
	3. Contam. Cont. Vent. Sys.	3.91 CFM	7,400 CFM	28,900	7,520 CFM	29,400
	4. Air Filtration Sys.	11.15/ CFM	6,900 CFM	78,900	7,050 CFM	78,600
	5. Emerg. Gen. Vent. & Cool. Sys.	6,500 Sys	1 Sys.	6,500	1 Sys.	6,500
	6. Balancing & Start-up	Lump Sum	-	11,400	-	11,400
	B. Plumbing Systems					
	1. Air Compressor Sys.	6,000/ Sys.	1 Sys.	6,000	1 Sys.	8,000
	2. Domestic Piping & Fixt.	36.63/ LF	1,000 LF	37,000	1,030 LF	37,900
	3. Perimeter Drain Sys.	23/ LF	920 LF	21,200	940 LF	21,600
	Water Well System	205,000/ Ea.	1 Ea.	205,000	1 Ea.	205,000
	D. Fire Protection System	1.34/ SF	24,000 SF	32,200	[illegible],100 SF	32,700
16	Electrical					
	A. Basic Elect. Service	38.87/ SF	36,400 SF	1,414,900	39,200 SF	1,523,700
	B. Lighting	.75/ SF	36,400 SF	27,300	39,200 SF	29,400
	C. Emerg. Generator Sys.	2.03/ SF	36,400 SF	73,900	39,200 SF	79,600
	D. UPS	2.14/ SF	36,400 SF	77,900	39,200 SF	83,900
	E. Fire Alarm & Monitor Sys.	.71/ SF	36,400 SF	25,800	39,200 SF	27,800
	Subtotal			$ 9,793,500		$11,296,600
	8% Contractor's Markup			783,500		903,700
	Subtotal			10,577,100		12,200,300
	15% Design Contingency			1,583,700		1,830,000
	Total Estimated Cost			$12,140,800		$14,030,300
	Total Square Footage			36,357		39,200
	Cost Per Square Foot			$ 334		$ 358
	25 Year Life Cycle Cost					
	Building			$14,276,000		$16,192,000
	Equipment			206,000		221,000
	Utilities			902,000		930,000
	Total			$15,384,300		$17,343,000

* Assume completion in 1984

…ATES OF PROBABLE CONSTRUCTION COST

	Concept 3		Concept 4		Concept 5		Concept 6	
Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
[illegible]738,590		$ [illegible]		$ 443,[illegible]		$ 431,400		$ 868,900
163,2[illegible]0	31,[illegible]0 CY	179,100	[illegible] CY	229,600	49,000 CY	274,400	82,357 CY	461,200
59,100	22,020 CY	[illegible]	31,[illegible] CY	96,400	30,700 CY	88,130	51,846 CY	148,800
747,300	29,[illegible]3 CY	1,747,600	30,[illegible]40 CY	[illegible]	30,525 CY	1,942,300	30,950 CY	1,969,400
59[illegible],400	354,[illegible]70 SF	529,300	392,750 SF	569,800	385,065 SF	573,900	390,460 SF	583,300
[illegible],709	3,1[illegible]8 Tons	3,938,560	3,421 Tons	4,317,500	3,442 Tons	4,342,800	3,490 Tons	4,404,500
482,700	434 Ea	433,600	532 Ea	532,[illegible]00	535 Ea.	535,300	543 Ea.	542,800
[illegible],300	4 Tons	[illegible]	[illegible]	5,000	7.9 Tons	9,900	3.4 Tons	4,200
500	30 LF	500	[illegible]	500	50 LF	500	30 LF	300
[illegible]7,300	39,[illegible]6 SF	320,000	54,44[illegible] SF	441,000	49,827 SF	403,600	55,555 LF	450,000
693,000	5 Ea.	643,000	[illegible] Ea.	693,[illegible]	5 Ea.	431,500	5 Ea.	693,000
16,000	2 Ea.	16,000	2 Ea	16,000	2 Ea	16,000	1 Ea.	8,000
40,100	26 Ea	42,100	22 Ea	44,100	15 Ea	78,100	27 Ea.	54,100
1,200	3 Ea.	1,200	3 Ea.	1,200	3 Ea.	1,200	3 Ea.	1,200
400	33 SF	400	33 SF	400	33 SF	400	33 SF	400
5,000	1 Lot	5,000	1 Lot	5,000	1 Lot	5,000	1 Lot	5,000
151,000	38,96[illegible] SF	150,000	37,[illegible] SF	144,300	34,212 SF	132,100	33,766 SF	130,[illegible]00
12,000	1 Lot	12,000	1 Lot	12,000	1 Lot	12,000	1 Lot	12,000
22,100	126 LF	22,100	126 LF	22,100	126 LF	22,100	80 LF	14,000
14,800	4 Ea.	4,800	4 Ea	14,800	4 Ea.	14,800	2 Ea.	7,400
4,500	1 Ea.	4,500	1 Ea	4,500	1 Ea.	4,500	1 Ea.	4,500
-	2 Ea	40,000	1 Ea	40,000	-	-	1 Ea.	40,000
5,000	-				-	-	-	
112,800	40 Tons	[illegible]	42 Tons	126,000	40 Tons	120,000	42 Tons	126,000
11,300	15 Tons	[illegible]	[illegible] Tons	12,600	15 Tons	12,600	15.8 Tons	12,600
29,400	8,300 CFM	[illegible]	[illegible] CFM	32,400	8,000 CFM	31,200	8,400 CFM	32,400
78,600	7,500 CFM	[illegible]	[illegible] CFM	87,400	7,[illegible]00 CFM	83,500	7,875 CFM	87,800
6,500	1 Sys.	[illegible]	[illegible]	6,500	1 Sys.	6,500	1 Sys.	6,500
11,400		12,000		12,6[illegible]	-	12,000	-	12,000
6,000	1 Sys.	6,000	1 Sys.	6,000	1 Sys.	6,000	1 Sys.	6,000
37,900	1,100 LF	40,300	1,15[illegible] LF	42,300	1,100 LF	40,300	1,135 LF	42,300
21,600	1,000 LF	[illegible]	[illegible] LF	24,200	1,000 LF	23,000	1,050 LF	24,200
205,000	1 Ea.	[illegible]	1 Ea	205,000	1 Ea.	205,000	1 Ea.	205,000
32,700	26,[illegible]00 SF	[illegible]	27,[illegible]00 SF	35,[illegible]00	26,000 SF	34,900	27,300 SF	34,900
[illegible]23,700	43,775 SF	[illegible]	44,[illegible] SF	[illegible]	44,020 SF	1,711,1[illegible]0	49,137 SF	1,910,000
29,400	43,775 SF	[illegible]	44,[illegible] SF	6,[illegible]00	44,020 SF	33,000	49,137 SF	36,900
79,600	43,775 SF	[illegible]	44,[illegible] SF	97,600	44,020 SF	49,400	49,137 SF	99,700
83,900	43,775 SF	[illegible]3,700	44,[illegible] SF	102,500	44,020 SF	44,200	49,137 SF	105,200
[illegible]7,800	43,775 SF	[illegible]	44,[illegible] SF	34,200	44,020 SF	31,300	49,137 SF	34,900
[illegible]96,500		$11,8[illegible]		[illegible],400		$12,[illegible]5,200		$13,279,800
403,700		949,[illegible]		1,[illegible]4,400		1,017,200		1,062,400
[illegible]00,300		12,8[illegible]		13,[illegible]4,800		13,[illegible]32,400		14,342,200
930,000		[illegible]		2,1[illegible],200		2,059,900		2,151,300
[illegible]30,[illegible]00		$14,[illegible]44,[illegible]		$1[illegible]		$15,[illegible]92,300		$16,49[illegible],500
[illegible]9,200		4[illegible]		49,100		44,020		49,137
358		$ 33[illegible]		$ 340		$ [illegible]59		$ 336
[illegible]92,000		$17,5[illegible],000		$16,01[illegible],000		$1[illegible],[illegible]29,000		$19,052,000
[illegible]21,300		[illegible]		[illegible]		[illegible]33,000		271,000
930,000		[illegible]		1,0[illegible]		[illegible]		1,075,000
543,300		$18,[illegible]		[illegible],342,[illegible]		[illegible]		$20,398,000

SECTION IV

COMPARATIVE ANALYSIS

The following table presents a comparative rating of the six facility concepts using six separate comparison factors. Three of the factors: efficiency, life cycle cost and total cost are strictly objective, while the other three factors are subjective, requiring judgement and knowledge of project objectives to apply ratings. In order to minimize any tendencies for bias ratings, the BJI project team applied the ratings independently and developed averages to arrive at a single rating for each subjective factor. Explanations of rating factors follow the table.

Based on total ratings for all factors and the rating scale (lowest total equal best rating), Concept No. 1 is the most favorable solution, Concept No. 3 is second and Concept No. 4 is third.

COMPARATIVE RATING TABLE

RATING FACTORS	CONCEPTS					
	No. 1	No. 2	No.3	No. 4	No. 5	No.6
Efficiency (Net-to-Gross Area Ratio)	5	4	6	2	1	3
Life Cycle Cost	1	4	2	3	5	6
Total Cost	1	2	3	5	4	6
Function	1	5	2	3	6	4
Security	3	4	2	1	5	6
Safety	1	2	4	6	3	5
TOTALS	12	21	19	20	24	30

Rating Scale: Highest = 1; Moderate = 3-4; Poorest = 6

1. Efficiency is defined as the "net" assignable area in relation to the "gross" space and is calculated by dividing the total net square feet by the total gross square feet.

$$\text{Efficiency} = \frac{\text{net square feet}}{\text{gross square feet}}$$

   Net square feet (area) is the area assigned for facility operation and includes circulation within a functional area, but not outside of it. Therefore, corridor and vestibule areas are excluded. Also, mechanical/electrical space is excluded. Gross square feet (area) is the total area within the building including structure, partitions, hallways, building support areas (such as mechanical/electrical areas, plenums, etc.) and toilets, also including 50 percent of the covered dock area.

2. Life cycle cost includes the 25 year cost of maintaining and operating the building and equipment.

3. Total cost includes the price for the facility construction including all architectural, mechanical, electrical, plumbing and structural.

4. Function is based on how well the building plan meets the "program" criteria. Involved in this analysis are considerations concerning building configuration (Does the "plan" lead to spaces larger than program requirements?), and the need for special equipment or conveying systems (Does the type of weapons storage or building configuration require additional cranes or hoists in order to perfrom the facility's function?).

5. Security is determined by facility accessibility and internal control.

6. Safety is rated both for personnel egress and internal safety in case of a hazard.

APPENDIX 4

DESIGN DRAWINGS

Plan and section drawings for the six baseline munition storage facilities are contained in the envelope attached to this volume of the report.

APPENDIX 4

DESIGN DRAWINGS

APPENDIX 5

CONCEPT DESIGN

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 13

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: DESIGN REQUIREMENT SUMMARY CONCEPT 1
BY: D KETCHUM DATE: 29 Sept 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

CONCEPT No. 1

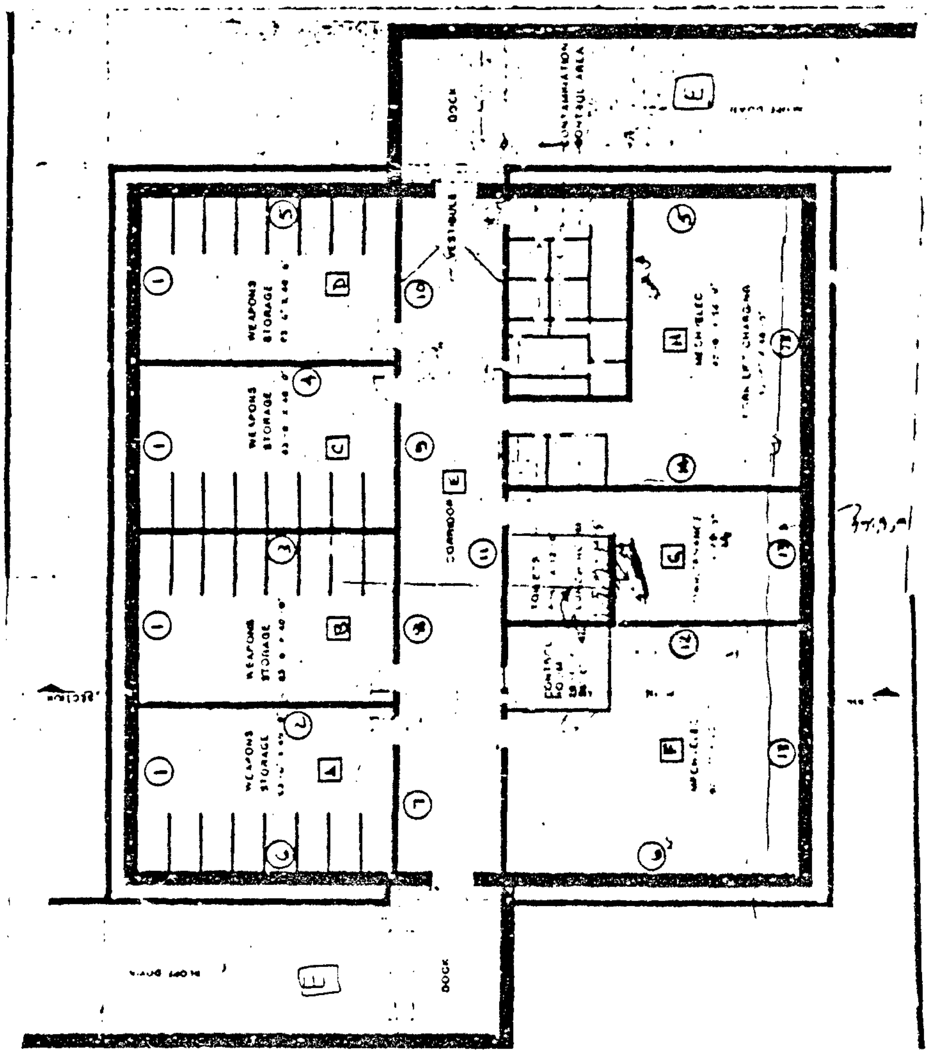
NOTE - NUMBERS = WALLS, LETTERS = ROOFS

WALL/ROOF	T(in)	BAR (F,L,S)	SIZE/SPACING SHORT SPAN	SIZE/SPACING LONG SPAN	SPAN (IN) OR (FT x FT)
1	48	FLEXURE	#11@12	#9@12	240"
		LACING			
2	24	F	#9@12	#6@12	216"
		L	5@12		
3	24	F	#7@12	#6@12	240"
		L	5@12		
4	24	F	#9@12	#6@12	216"
		L	5@12		
5	48	F	#9@12	#9@12	240"
		L			
6	48	F	#9@12	#9@12	240"
		L			
7,8,9,10	24	F	#9@12	#6@12	36"
		L	#7@12		
11,12,14	24	F	(2)#9@12	#6@12	240"
		L	#7@12		
13	48	F	#11@12	#11@12	240"
		L			
A	48	F	#11@12	#9@12	
		L			63'x40'
		STIRRUP	#5@12		
B	48	F	#11@12	#9@12	
		L			63'x40'
		S	#5@12		
C	48	F	#11@12	#9@12	
		L			63'x40'
		S	#5@12		
D	48	F	[illegible]	#9@12	
		L			63'x40'
		S	[illegible]		
E	72	F	(3)#10@12	#9@12	
		L			30' 1-WAY
		S	#5@12		
F	48	F	#11@12	#11@12	
		L			60'x73'
		S	#5		
G	48	F	#11@12	#11@12	
		L			31'x48'
		S	#5		
H	48	F	#11@12	#11@12	71'x42'
		L			
		S	#5@12		

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 2 OF 13

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: CONCEPT I DOUBLE STACKED
BY: D KETCHUM DATE 24 SEPT 19 82 CHECKED BY: DATE CHECKED: 19



SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO 3 OF 13

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Design Requirement Summary Concept 2
BY: [illegible] DATE: [illegible] 19 92 CHECKED BY: DATE CHECKED 19

Concept No. 2

NOTE: LETTERS = ROOFS, NUMBERS = WALLS

Wall/Roof	T(in)	Bar (F,L,S)	Size/Spacing Short Span	Size/Spacing Long Span	Size (in) or (Ft x Ft)
1	48	F	#11@12	#11@12	240"
		L	#5		
2	48	F	#11@12	#11@12	240"
		L	#5		
3	48	F	#11@12	#11@12	240"
		L	#5		
4	48	F	#11@12	#11@12	240"
		L	#5		
5,6	24	F	#10@12	#6@12	240"
		L	#5 mats 2		
7,8,12,13	24	F	#10@12	#6@12	244
		L	#5 m 2		
9	48	F	#11@12	#11@12	
		L			
10,11	24	F	(2)#10@12	#6@12	240"
		L	#7@12		
A	48	F	#11@12	#11@12	71 x 42
		S	#5		
B	48	F	#11@12	#11@12	71 x 42
		S	#5		
C	48	F	#11@12	#11@12	71 x 44
		S	#5		
D	48	F	#11@12	#11@12	71 x 44
		S	#5		
E	72	F	3#10@12	#9@12	30' 1-WAY
		S	#5		
F	48	F	#11@12	#11@12	71 x 44
		S	#5		
G	48	F	#11@12	#11@12	45 x 40
		S	#5		
H	48	F	#11@12	#11@12	71 x 44
		S	#5		

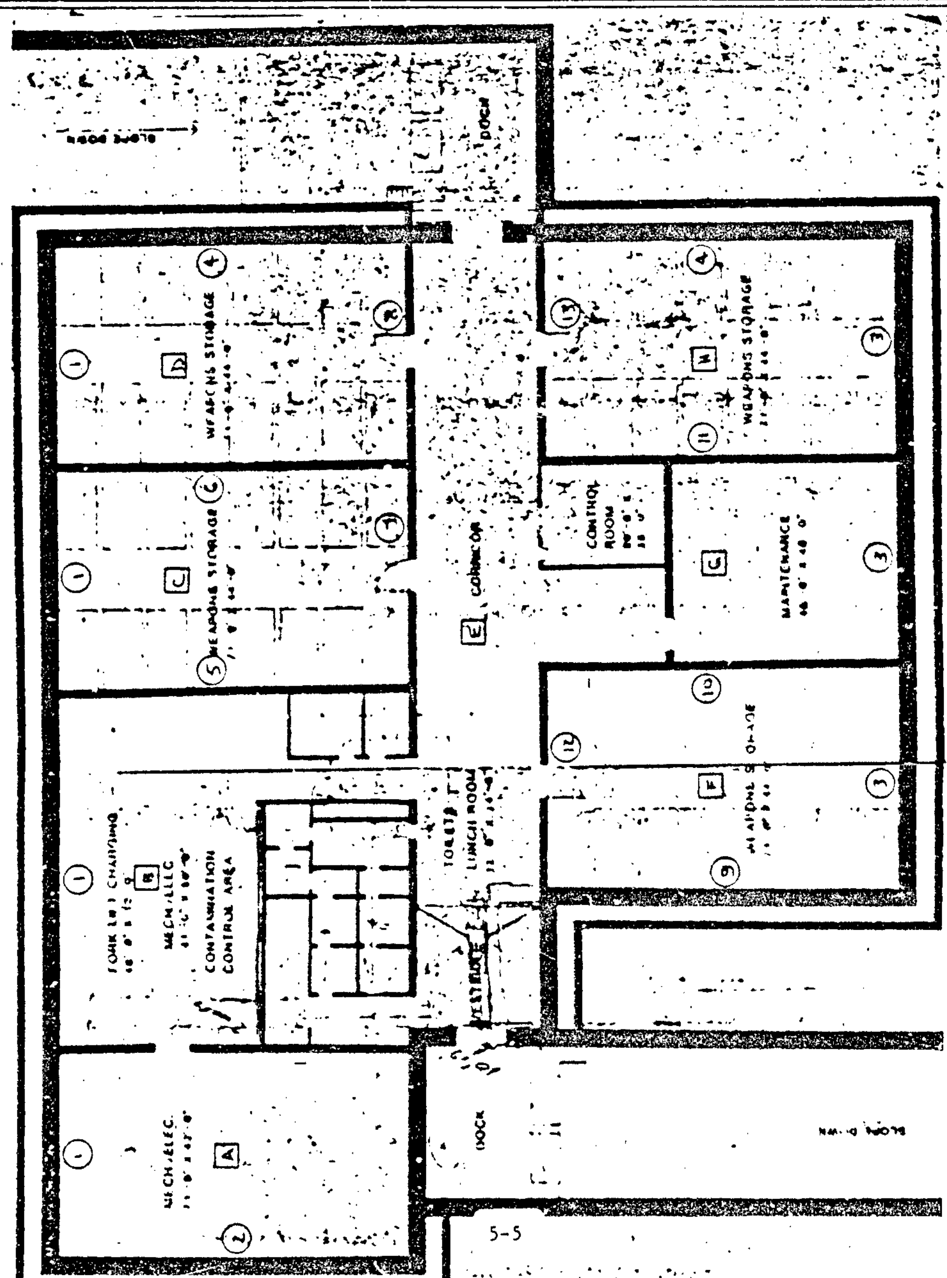
SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 4 OF 13

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT: Concept 2 - Pits

BY: ______ DATE: ______ 19 ____ CHECKED BY: ______ DATE CHECKED: ______ 19 ____



SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Design Requirement Summary Concept 3
BY: [illegible] DATE: 28 Sep 19 82 CHECKED BY: DATE CHECKED: 19

Notes: Numbers = Walls, Letters = Roofs

Concept No. 3

Wall/Roof	Tc(in)	Bar (F,L,S)	Size/Spacing Short Span	Size/Spacing Long Span	Size (in) or (Ft x Ft)
1	48	F	#11@12	#6@12	492"
		L			
2,11	48	F	#9@12	#6@12	492"
		L			
3,13	48	F	#11@12	#6@12	492"
		L			
4	24	F	#9@12	#6@12	216"
		L	#5 m2		
5,6,7	24	F	#9@12	#6@12	96"
		L	#5 m2		
10,12	48	F	#11@12	#6@12	492"
		L			
A,B,D,E	48	F	#11@12	#9@12	63 x 40'
		S	#5		
C	72	F	(3) #10@12	#9@12	30' 1-way
		S	#5		
9	24	F	#7@12	#6@12	240"
		L	#5 m2		
Ceiling/Floor	36	F	(2) #9@12	#7@12	80' x 156'
		L	#5 m2		

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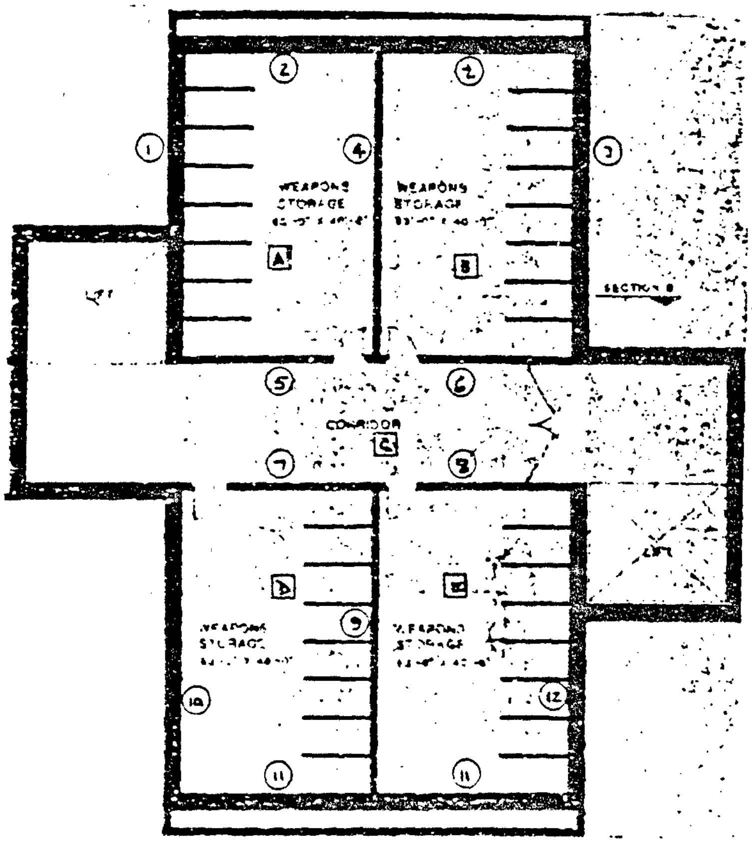
SHEET NO. 6 OF 13

PROJECT NO.: 02-7092 SPONSOR: C[illegible]
SUBJECT: [illegible] BELOW GRADE
BY: DATE: 19 CHECKED BY: DATE CHECKED: 19



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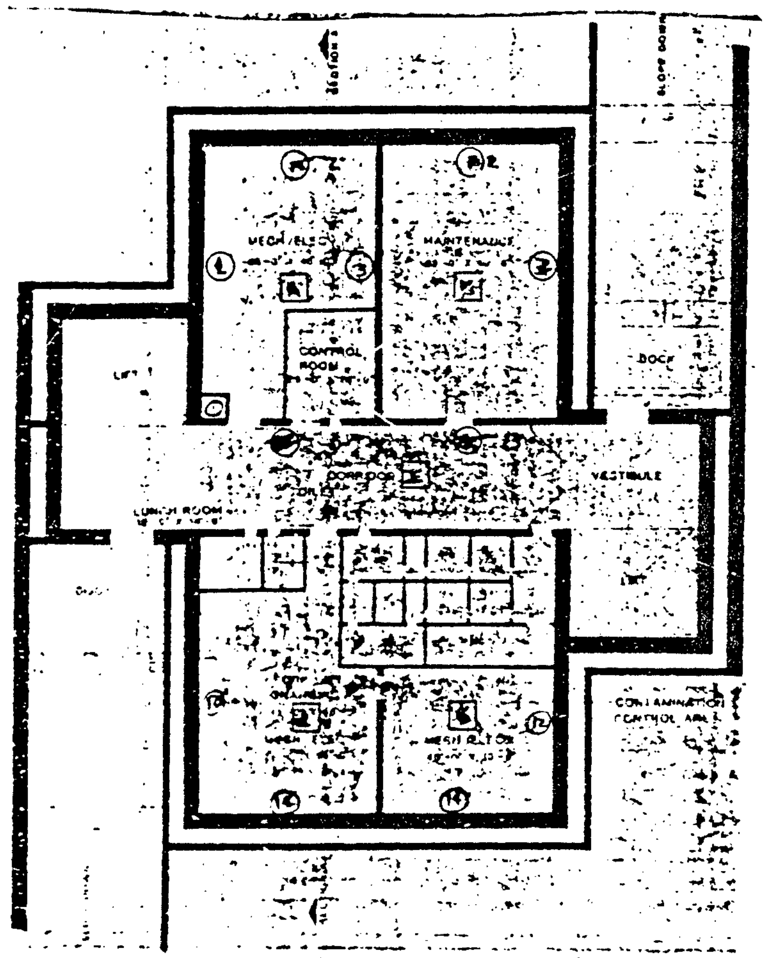
SHEET NO. 7 OF 13

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Concept #3 - Double Structure - Above Grade
BY: DYETRUM DATE: 24 Feb 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___



PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Design Requirement Summary
BY: D Ketchum DATE: 20 Sept 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ______

Concept 4

NOTE - Numbers = Walls; Letters = Roofs

Wall/Roof	T_c (in)	Bar (F,L,S)	Size/Spacing Short Span	Size/Spacing Long Span	Size (in) or (ft x ft)
1,3	24	F	#7@12	#6@12	156"
		L	#5@12		
2	24	F	#7@12	#6@12	144"
		L	#5@12		
4,5,6,7	24	F	#9@12	#6@12	144"
		L	#5@12		
8,9,10	24	F	(2) #9@12	#6@12	240"
		L	#7@12		
11	36	F	#10@12	#10@12	240"
		L			
12	36	F	#10@12	#10@12	240"
		L			
13	36	F	#9@12	#9@12	156"
		L			
14	36	F	#11@12	#9@12	156"
		L			
15	36	F	#9@12	#9@12	156"
		L			
16	36	F	#10@12	#10@12	240"
		L			
A	36	F	#11@12	#9@12	26' 1-WAY
		S	#5		
B	36	F	#11@12	#9@12	26' 1-WAY
		S	#5		
C	36	F	#11@12	#9@12	26 1-WAY
		S	#5		
D	36	F	#11@12	#5@12	26' 1-WAY
		S	#5		
E	48	F	#[illegible]@12	#5@12	25' 1-WAY
		S	#5		
F	36	F	#10@12	#10@12	52' x 48'
		S	#5		
G	36	F	#10@12	#[illegible]@12	52' x 42'
		S	#5		
H	36	F	#8@12	#9@12	37' x 54'
		S			
I	36	F	#10@12	#10@12	62' x 54'
		S	#5		

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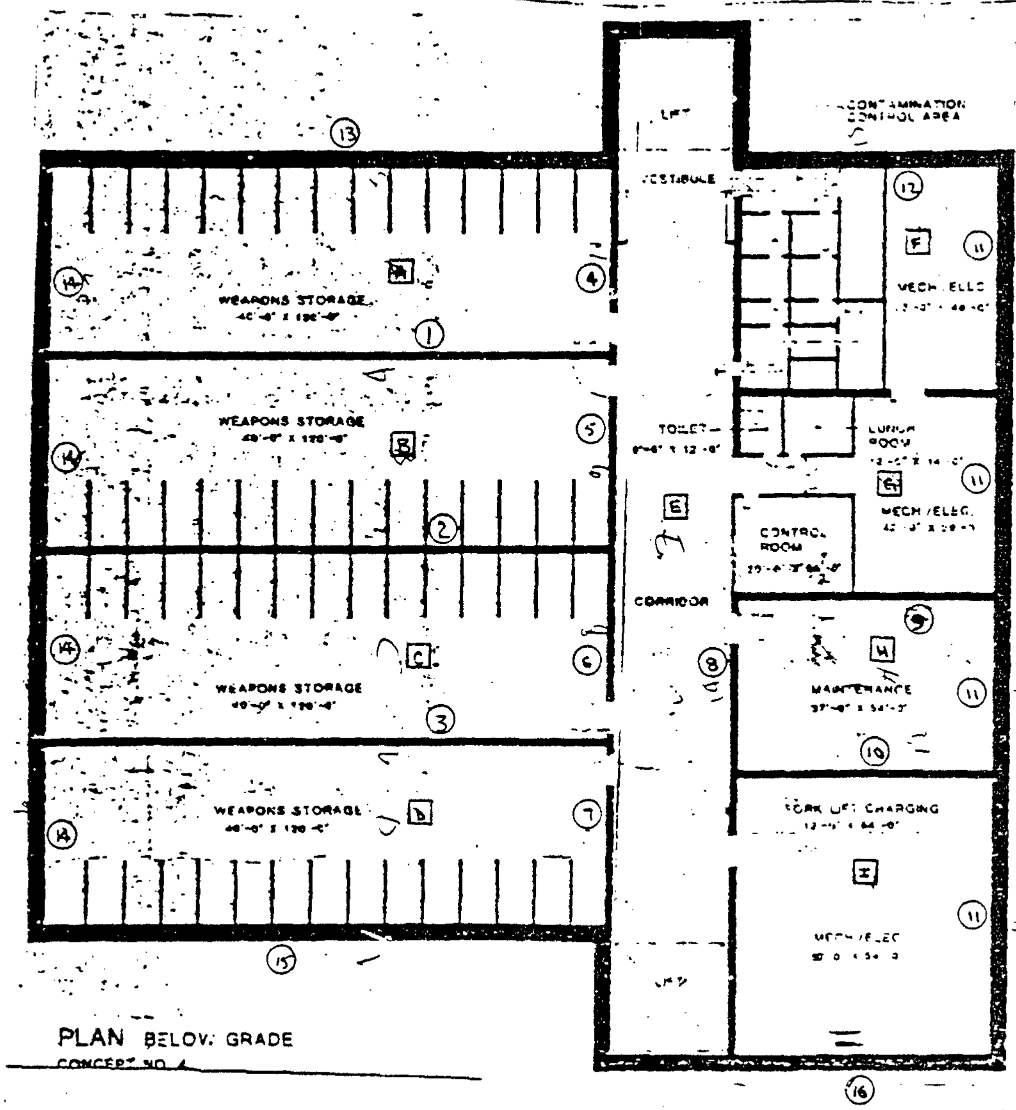
SHEET NO. 9 OF 13

PROJECT NO.: 02-7392 SPONSOR: CERL
SUBJECT: CONCEPT 4 LONG BAY
BY: DATE: 19 CHECKED BY: DATE CHECKED: 19



PLAN BELOW GRADE
CONCEPT NO. 4

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SHEET NO. 10 OF 13

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Design Requirement Summary Concept 5
BY: [illegible] DATE: [illegible] 19 82 CHECKED BY: DATE CHECKED: 19

Concept No. 5

Note: Letters = Roofs, Numbers = Walls

Wall/Roof	Tc (in)	Bar (F, L, S)	Size/Spacing Short Span	Size/Spacing Long Span	Size (in) or (Ft x Ft)
1	36	F L	#11@12	#6@12	240"
2	36	F L	(2)#9@12	#6@12	240"
3,4,17,18	24	F L	#7@12 #5@12	#6@12	240"
5	36	F L	#11@12	#6@12	240"
6,7,9,10	24	F L	#10@12 #5@12	#6@12	240"
11,12,13,14	24	F L	(2)#9@12 #7@12	#6@12	240"
15	36	F L	#11@12	#6@12	240"
16	36	F L	(2)#9@12	#6@12	240"
19	36	F L	(2)#9@12	#6@12	240"
A	36	F S	#10@12 #5	(2)#9@12	46'x71'
B	36	F S	#10@12 #5	(2)#9@12	46'x71
C	36	F S	#11@12 #5	(2)#9@12	57x71
D	36	F S	(2)#9@12	#6@12	25' 1-WAY
E	36	F S	(2)#9@12	#6@12	25' 1-WAY
F	36	F S	#10@12 #5	(2)#9@12	46'x71'
G	36	F S	#11@12	#11@12	42x46
H	36	F S	#10@12 #5	(2)#9@12	46'x71'
I	36	F S	#11@12 #5	(2)#9@12	57x71'

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SHEET NO. 11 c 13

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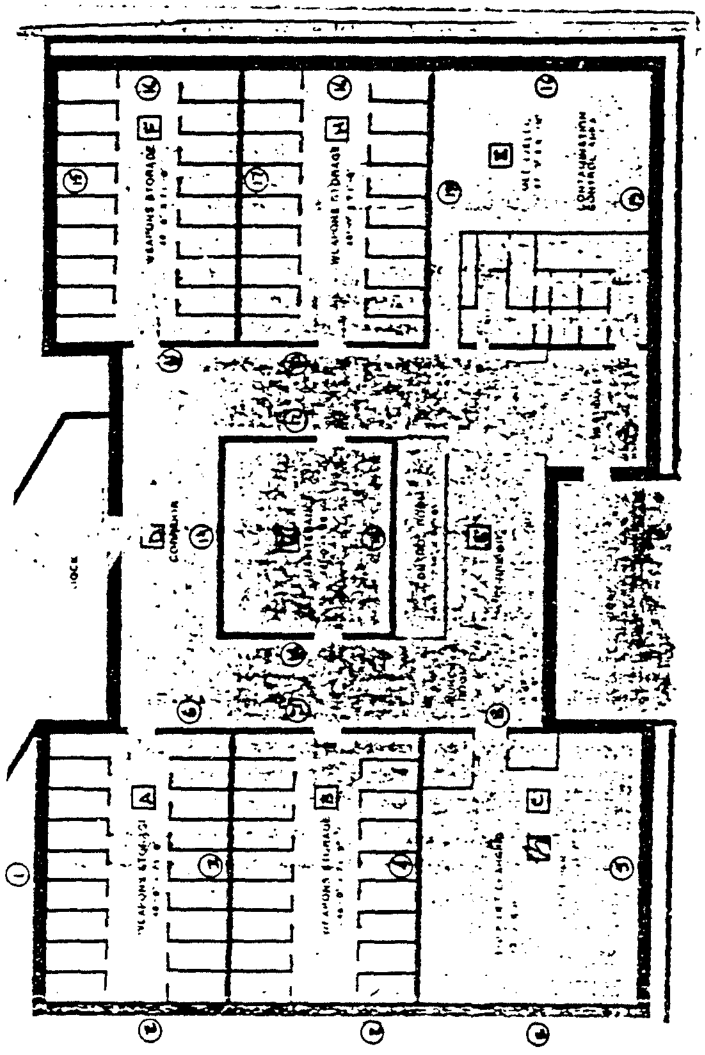
SUBJECT: CONCEPT 5 MAZE
BY: ______ DATE: ______ 19 __ CHECKED BY: ______ DATE CHECKED: ______ 19 __



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SHEET NO. 12 OF 13

PROJECT NO.: 02 7092 SPONSOR: CERL
SUBJECT: Design Requirement Summary Concept 6
BY: [illegible] DATE: [illegible] 19 92 CHECKED BY: DATE CHECKED: 19

Concept No. 6

Note: Numbers = Walls, Letters = Roofs

Wall/Roof	Tc(in)	Bar (F,L,S)	Size/Spacing Short Span	Size/Spacing Long Span	Size(in) or (ft x ft)
1,13	36	F	#11@12	#6@12	156"
		L			
2,12	36	F	#9@12	#6@12	156"
		L			
3,11	36	F	#11@12	#6@12	156"
		L			
4,6,14,16	24	F	#9@12	#6@12	144"
		L	#5@12		
5,17	36	F	#11@12	#6@12	156"
		L			
7,15	36	F	#11@12	#6@12	156"
		L			
8,18	36	F	#9@12	#6@12	156"
		L			
9	36	F	#10@12	#6@12	240"
		L			
10	36	F	#10@12	#6@12	240"
		L			
19,20,21	24	F	(2)#9@12	#6@12	240"
		L	#7@12		
A	36	F	#11@12	#9@12	26' 1-WAY
		S	#5		
B	36	F	#11@12	#9@12	26' 1-WAY
		S	#5		
C	36	F	#11@12	#9@12	26' 1-WAY
		S	#5		
D	36	F	#11@12	#9@12	26' 1-WAY
		S	#5		
E	36	F	#11@12	#9@12	25' 1-WAY
		S	#5		
F	36	F	#10@12	#10@12	40x53
		S	#5		
G	36	F	#10@12	#10@12	40x40
		S	#5		
H	36	F	#10@12	#10@12	40'x53'
		S	#5		
I	36	F	#8@12	#9@12	40'x40'
		S	#5		

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SUBJECT:

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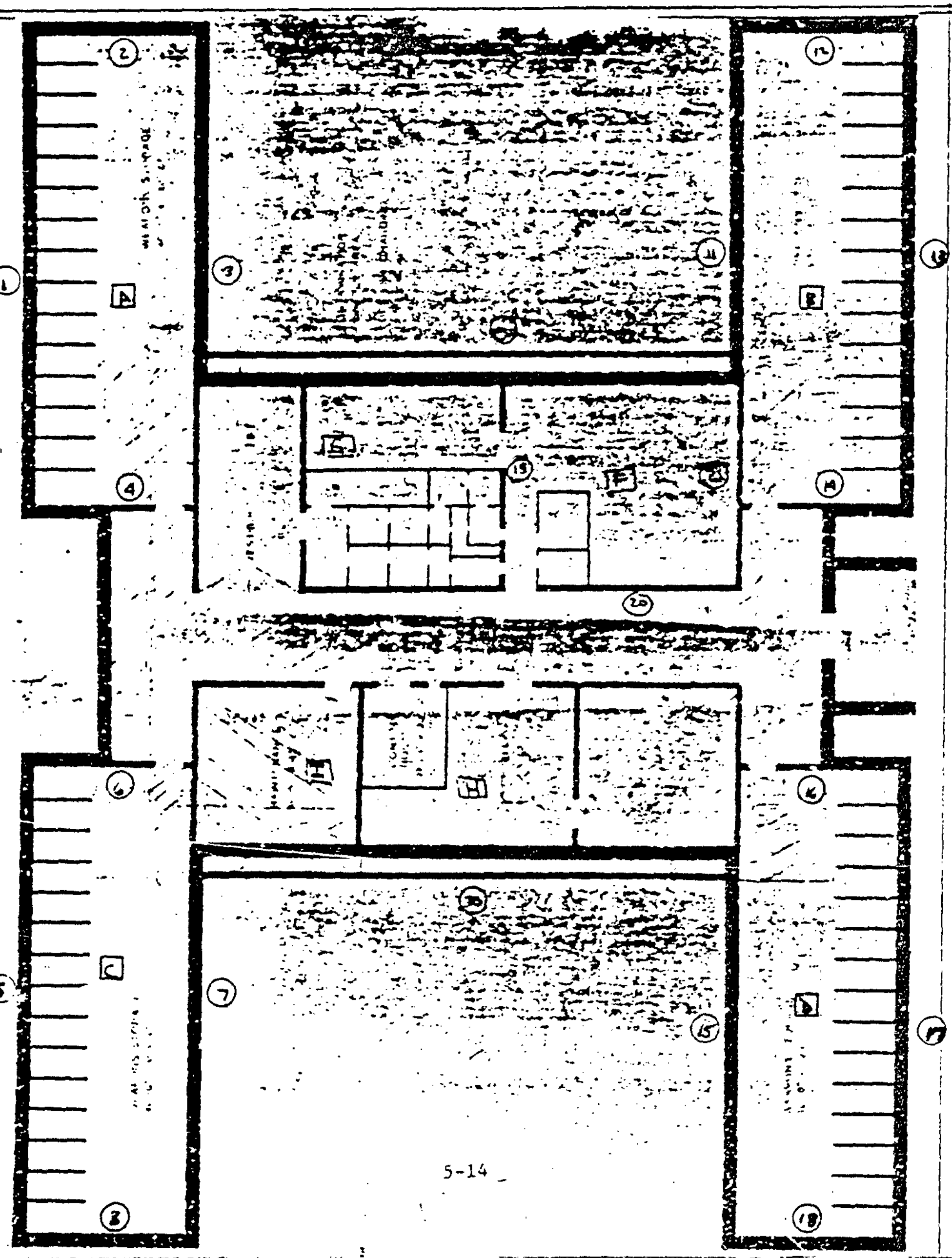

DISCUSSION OF METHODS USED

THE ANALYSIS BY SWRI INCLUDED CONSIDERATION OF THE FOLLOWING ITEMS

1. INTERNAL EXPLOSION BLAST LOADS
2. WEAPONS AND MAINTENANCE BAY STRUCTURAL DESIGN
3. EXTERIOR SHELL STRUCTURAL DESIGN FOR AIRCRAFT IMPACT

1. INTERNAL BLAST LOADS

WHEN AN EXPLOSION OCCURS IN A CONFINED OR PARTIALLY CONFINED STRUCTURE THE PRESSURE HISTORY EXPERIENCED BY WALL AND ROOF SURFACES CONSISTS OF TWO DISTINCT PHASES. THE FIRST PHASE IS THE SHOCK LOADING PHASE WHICH CONSISTS OF A VERY SHORT DURATION, HIGH PRESSURE PULSE FOLLOWED BY SEVERAL PRESSURE PULSES OF INCREASINGLY LOWER MAGNITUDE AS THE BLAST WAVE REVERBERATES WITHIN THE STRUCTURE. THIS FIRST PHASE IS A FUNCTION OF CHARGE WEIGHT AND STANDOFF. THE SECOND PHASE IS CALLED THE QUASI-STATIC PHASE AND IS A LONGER DURATION PRESSURE PULSE WHOSE PEAK MAGNITUDE IS DETERMINED BY CHARGE WEIGHT AND ROOM VOLUME. THE DURATION OF THE QUASI-STATIC PHASE IS FIXED BY THE AVAILABLE VENT AREA, PEAK QUASI-STATIC PRESSURE, AND ROOM VOLUME.

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SUBJECT: DISCUSSION OF METHODS USED
BY: M. WHITNEY DATE: 23 Sept 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

SHOCK PHASE – FIGURES 1-3, FROM REF. [1] WERE USED TO DEFINE INTERNAL SHOCK LOADING PARAMETERS INCLUDING IMPULSE AND PRESSURE. FIGURES 1 AND 3 WERE USED TO CALCULATE IMPULSE LOADS AS FOLLOWS. FOR THE CALCULATION OF AVERAGE PEAK SHOCK PRESSURE OVER A PLATE, FIGURES 1 AND 4 WERE USED. FIGURE 4 WAS USED FOR VALUES OF X/R WITHIN THE RANGE SHOWN, AND FIGURE 1 WAS USED FOR 2W (SIMILAR TO THAT DONE FOR IMPULSE) AND X/R GREATER THAN THAT SHOWN IN FIG 4.

ONCE SHOCK IMPULSE AND PRESSURE WERE OBTAINED AS DESCRIBED ABOVE, A SHOCK DURATION, t_d, WAS SOLVED FOR ASSUMING A TRIANGULAR PULSE AS DESCRIBED IN IN REF. (1), i.e. $t_d = 2\frac{i}{P}$. A FACTOR OF 1.75 WAS USED, WHERE APPLICABLE, TO P AND i TO ACCOUNT FOR SHOCK REVERBERATIONS AS SUGGESTED IN REF (1), AND t_d IS THEREBY KEPT THE SAME.

QUASI-STATIC PHASE – PEAK QUASI-STATIC PRESSURE AND DURATION WERE CALCULATED USING FIGURE 5 FROM DOE/TIC-11268 (1). FIGURE 5 GIVES PEAK QUASI-STATIC PRESSURE AS A FUNCTION OF CHARGE WEIGHT AND ROOM VOLUME.

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BY: WHITNEY DATE: 27 Sept 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

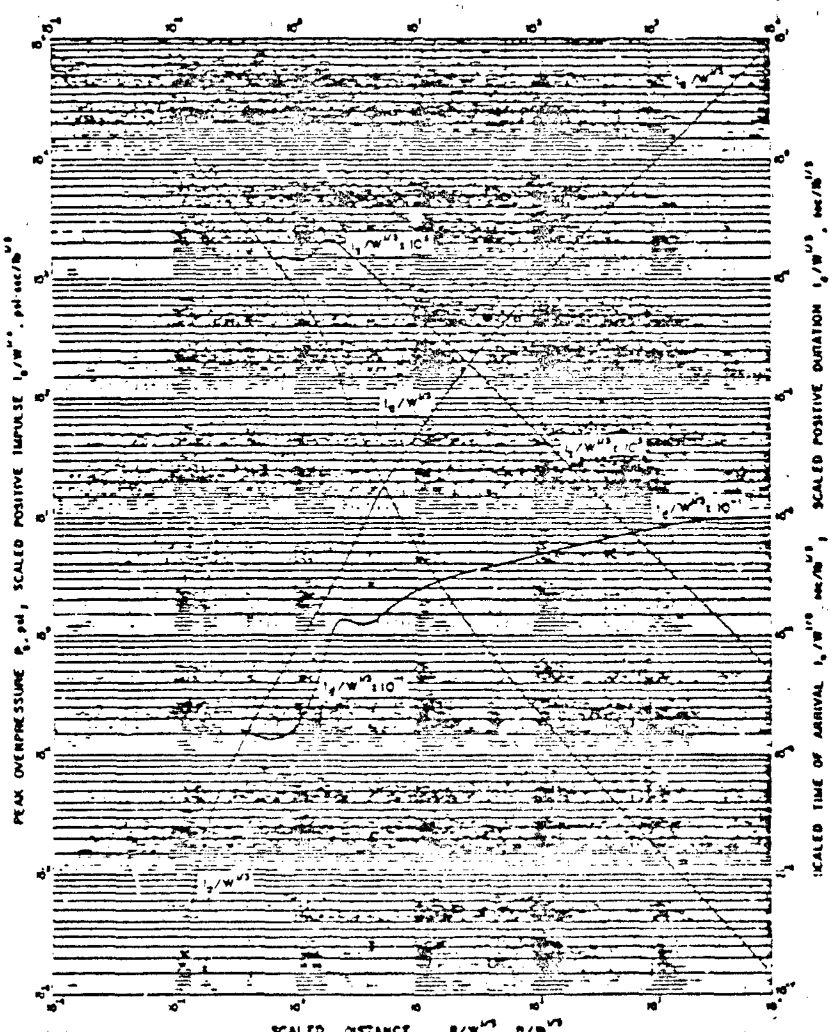

FIGURE 1 - SIDE-ON BLAST WAVE PROPERTIES FOR BARE SPHERICAL TNT FOR AN EXPLOSION IN AIR
(FROM REF. 1, FIGURE 4.5)

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SHEET NO. 9 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
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BY: W. WHITNEY DATE: 25 Jan 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

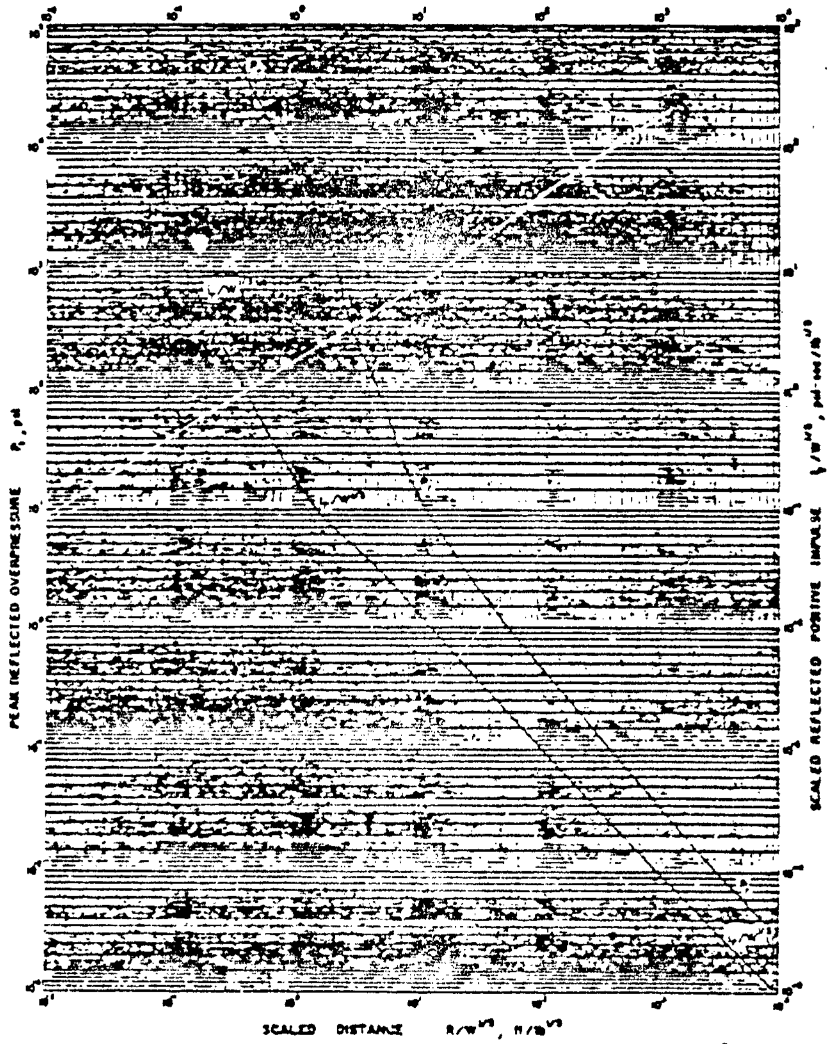

FIGURE 2. NORMALLY REFLECTED BLAST WAVE PROPERTIES FOR BARE, SPHERICAL TNT FOR AN EXPLOSION IN AIR (REF. (1), FIGURE 4.6)

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I/W**1/3 VS X/R FOR VARIOUS Z VALUES

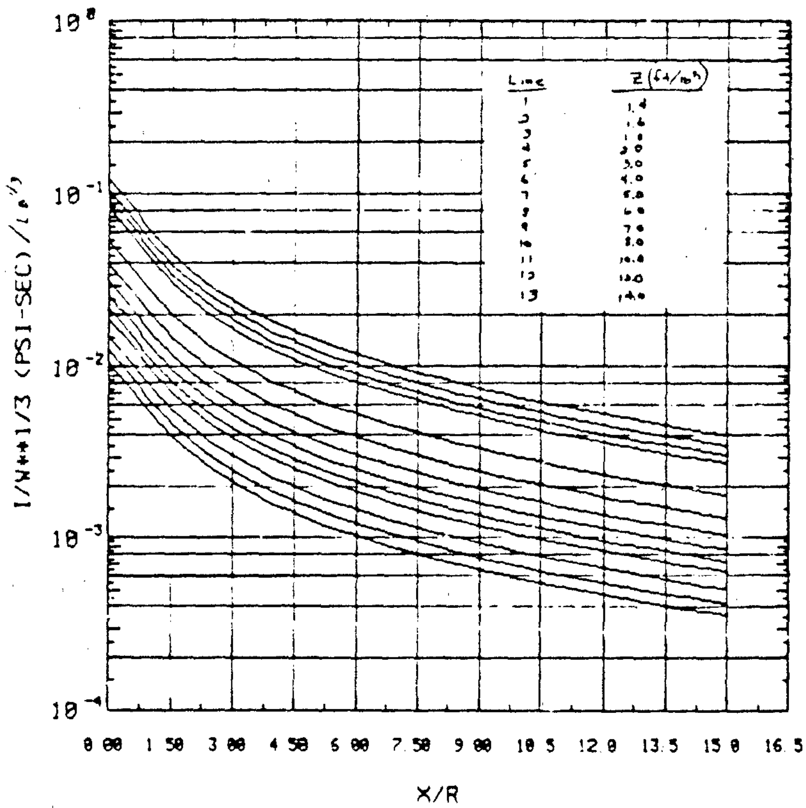

FIGURE 3a. SPECIFIC IMPULSE, $1.4 \leq Z \leq 14.0$

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PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Discussion
BY: H. WHITNEY DATE: 27 Sept 1982 CHECKED BY: DATE CHECKED: 19

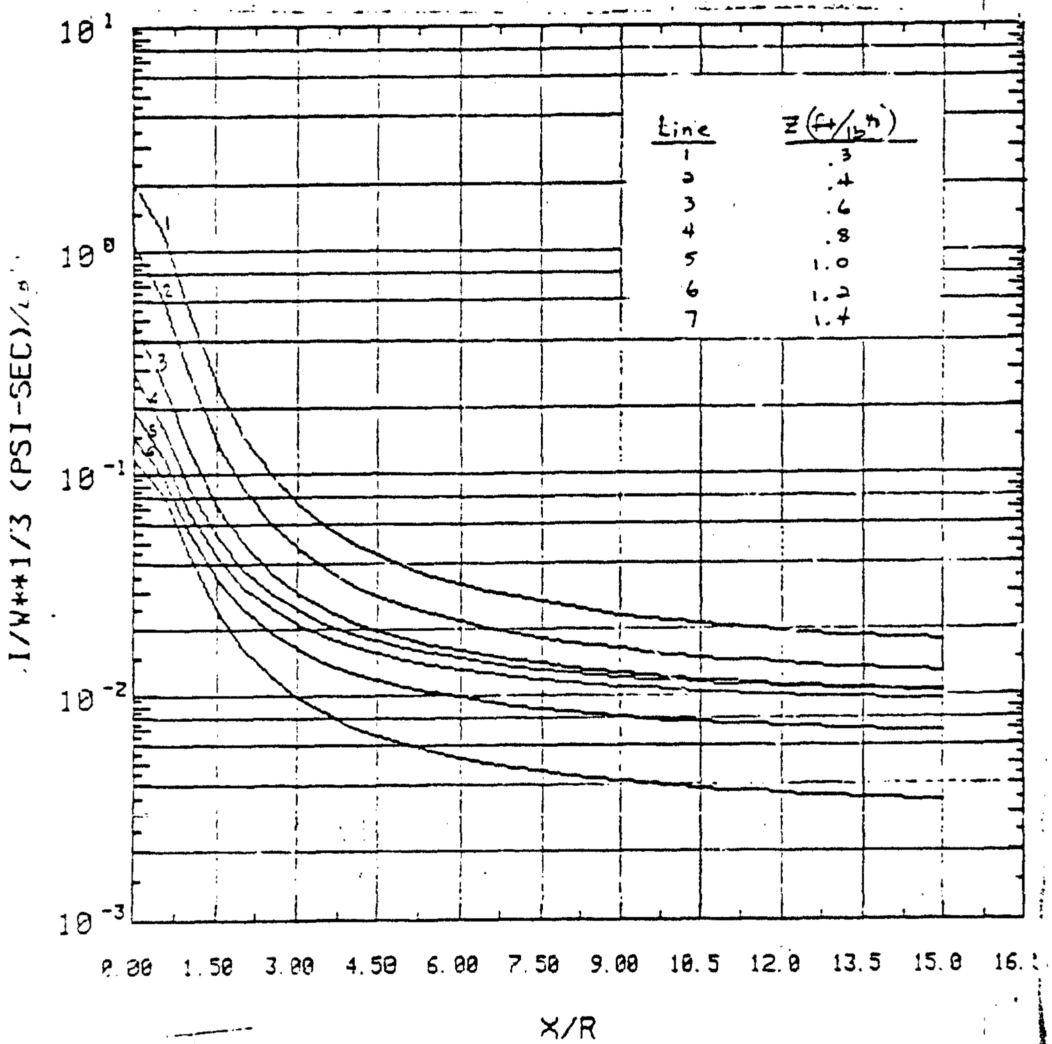

FIGURE 36. SPECIFIC IMPULSE, $0.3 \le Z \le 1.4$

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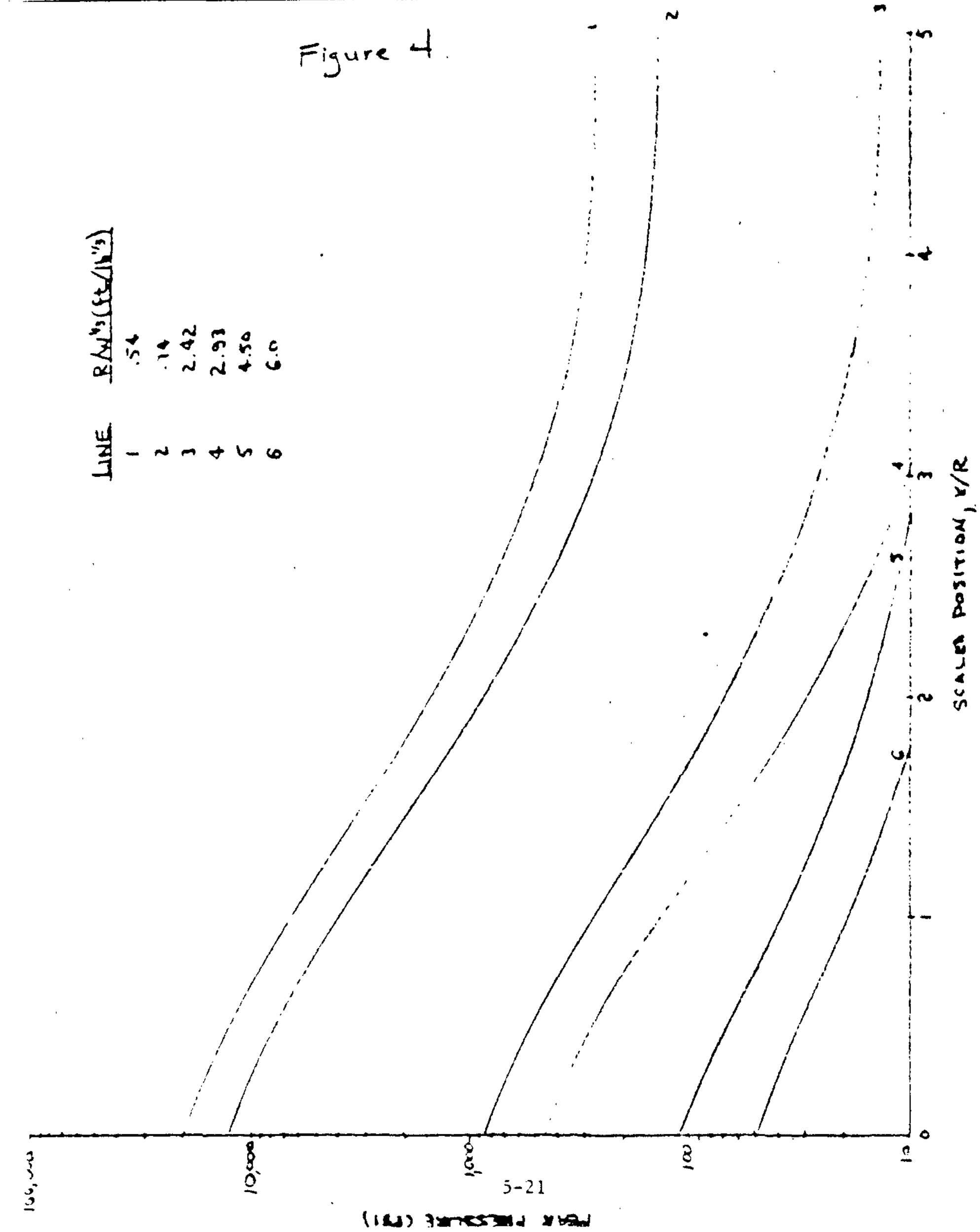
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: PEAK PRESSURE VS. SCALED POSITION FOR DIFFERENT SCALED POSITIONS
BY: D KETCHUM DATE: 30 SEPT 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

Figure 4



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PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: DISCUSSION
BY: H. WHITNEY DATE: 25 Sept 19 82 CHECKED BY: DATE CHECKED: 19

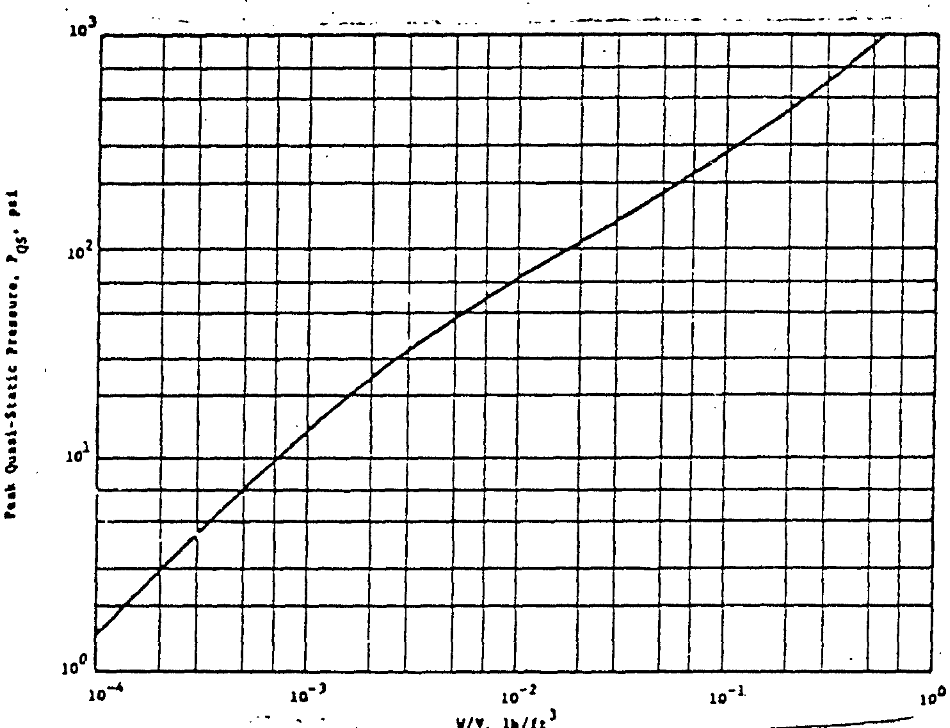

Figure 5 PEAK QUASI-STATIC PRESSURE FOR TNT EXPLOSION IN CHAMBERS

(REF. (1), FIG. 4.43)

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SUBJECT: DISCUSSION
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BEFORE ANY BLAST CALCULATIONS ARE MADE, THE SPECIFIED EXPLOSIVE WT IS INCREASED BY A 1.2 FACTOR AS SUGGESTED IN TM5-1300 [2].

2. WEAPONS AND MAINTANCE BAY STRUCTURAL DESIGN

THE WALLS WERE DESIGNED AS FIXED - FIXED ONE WAY MEMBERS SPANNING FROM FLOOR TO CEILING. DIVIDING WALLS WERE TREATED EITHER AS FIXED - FIXED OR CANTILIVER AS NECESSARY. 1° OF ROTATION WAS CHOSEN FOR REUSABLE DESIGN FOR WALLS AND 12° ROTATION FOR DIVIDING WALLS. THE ROOF SLAB DESIGNS ARE SET BY THE AIRCRAFT IMPACT EXCEPT FOR ONE CASE. THIS WAS TREATED AS A FOUR-SIDED FIXED TWO WAY SLAB. THE ONE WAY DESIGN WAS TREATED AS FOLLOWS:

A COMPUTER PROGRAM, "BEAMDES", USING BIGGS' METHOD AS DESCRIBED IN TM5-1300 (2) AND THE U.S. ARMY SUPPRESSIVE SHIELDS HANDBOOK (3), WAS WRITTEN AT SwRI TO DESIGN ONE-WAY REINFORCED CONCRETE MEMBERS. THIS METHOD CONVERTS A DYNAMICALLY LOADED STRUCTURE WITH DISTRIBUTED MASS AND LOADS, TO AN EQUIVALENT ONE DEGREE-OF-FREEDOM STRUCTURE. THE PROGRAM ACCOUNTS FOR THE COMBINED EFFECT OF THE SHOCK AND QUASI-STATIC LOADS.

THE DESIGN PROCESS USED BY SwRI, EMPLOYING THE "BEAMDES" COMPUTER CODE, IS PRESENTED IN FLOWCHART FORM AS FIGURE 6. PRELIMINARY STRUCTURAL DESIGNS WERE MADE USING PRELIMINARY BLAST LOADS. THE "BEAMDES" CODE ENABLED SwRI TO DETERMINE THE REQUIRED STEEL AREAS FOR VARIOUS VALUES OF SUPPORT ROTATION, WALL THICKNESS AND SUPPORT CONDITIONS.

THE NEXT STEP WAS TO DESIGN THE LACING REINFORCEMENT AND DESIGN FOR SUPPORT REACTIONS, ACCORDING TO TM5-1300 (2). THESE PROCEDURES WILL NOT BE DESCRIBED IN DETAIL HERE SINCE CHAPTERS 5, 6 & 9 DISCUSS THESE METHODS FULLY USING EXAMPLE PROBLEMS.

DOCUMENTATION OF THE "BEAMDES" CODE FOLLOWS.

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SHEET NO 11 19

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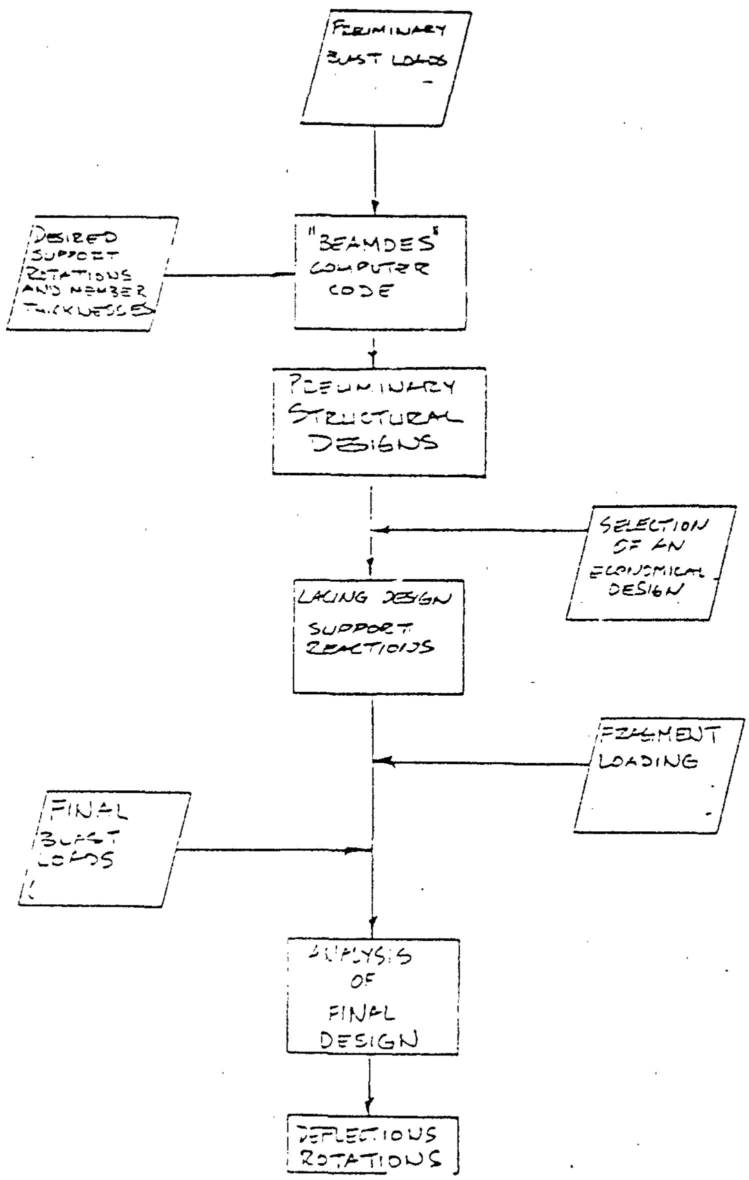

Fig 6 ONE-WAY REINFORCED CONCRETE DESIGN PROCESS

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PROJECT NO.: 02-7092 SPONSOR: CERL
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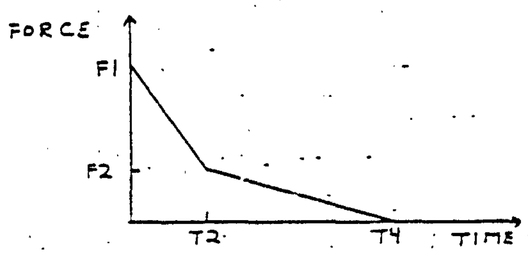
BY: B Moon DATE: 29 Sept 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

THE "BEAMDES" PROGRAM WAS WRITTEN TO PROVIDE A MEANS OF DESIGNING REINFORCED CONCRETE BEAMS AND ONE-WAY SLABS IN ACCORDANCE WITH TM 5-1300[2]. REQUIRED INPUT, COMPUTATIONAL SCHEME AND OUTPUT ARE DESCRIBED BELOW.

THE PROGRAM USES THE FORCE-TIME LOADING FUNCTION AS SHOWN. THE FORCES F1 AND F2 REPRE-



FORCE-TIME FUNCTION

SENT THE PEAK SHOCK AND QUASI-STATIC PRESSURES, RESPECTIVELY, MULTIPLIED BY THE BEAM LENGTH, L, MULTIPLIED BY 1.0 INCH FOR A UNIT STRIP. END SUPPORT CONDITIONS OF FIXED-FIXED, FIXED-PINNED OR PINNED-PINNED ARE ALSO INPUT. MATERIAL PROPERTY INPUTS CONSIST OF THE CONCRETE CRUSHING STRENGTH, F_c', AND THE STEEL DYNAMIC

YIELD STRENGTH, FDY. THE DESIRED MAXIMUM ROTATION IS INPUT, AS IS THE TOTAL THICKNESS OF THE CONCRETE SECTION AND THE THICKNESS OF COVER ABOVE OR BELOW THE TENSION AND COMPRESSION STEEL. THE MOMENT ARM OF THE REINFORCING STEEL, d_c, IS CALCULATED FROM THESE INPUTS. A DOUBLY REINFORCED CONCRETE SECTION IS ASSUMED WITH EQUAL TENSION AND COMPRESSION AREAS AND BAR STRENGTHS.

THE SOLUTION PROCEDURE IS AN ITERATIVE ONE IN WHICH THE AREA OF TENSION AND COMPRESSION STEEL IS VARIED BETWEEN 0.01 IN^2/IN AND 3.0 IN^2/IN OF BEAM/SLAB WIDTH. AN AVERAGE MOMENT OF INERTIA, I_A, FOR THE SECTION IS CALCULATED USING EQUATIONS 5-20, 5-21 AND 5-22 OF TM5-1300. THE ULTIMATE MOMENT CAPACITY OF THE SECTION, M_u, IS CALCULATED AS $M_u = A_s F_{DY} d_c$ PER EQN. 5-7 OF TM5-1300.[2] THE ELASTIC AND ELASTIC-PLASTIC STIFFNESSES, KEL AND KELPL, ARE THEN DETERMINED FOR THE APPROPRIATE END SUPPORT CONDITIONS USING TABLE 5-11 OF TM 5-1300.[2] THE CODE THEN CALCULATES THE

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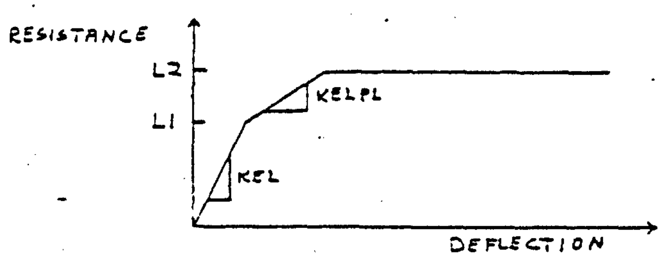
BY: B Thomas DATE: 23 Sept 1987 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

ELASTIC AND PLASTIC MAXIMUM RESISTANCES, L1 AND L2, BASED ON TABLES FOUND IN "SUPPRESSIVE SHIELDS",[3] HNDM-1110-1-2, AND BIGGS' INTRODUCTION TO STRUCTURAL DYNAMICS.[4] THE TOTAL RESISTANCE-DEFLECTION RELATIONSHIP IS SHOWN BELOW. APPROPRIATE



RESISTANCE - DEFLECTION CURVE

LOAD-MASS FACTORS, K_{LM}, ARE ALSO DETERMINED BASED ON BIGGS[4] AND TM 5-1300.[2]

ONCE ALL OF THE ABOVE INPUT PARAMETERS FOR A SINGLE-DEGREE-OF-FREEDOM SIMULATION ARE ESTABLISHED, THE CODE CALCULATES THE MAXIMUM DEFLECTION OF THE BEAM/SLAB USING A NUMERICAL TECHNIQUE OUTLINED IN BIGGS. THIS CALCULATED MAXIMUM DEFLECTION IS COMPARED WITH THE DESIRED DEFLECTION, AND, IF IT DIFFERS BY MORE THAN 1%, THE AREA OF STEEL IS ADJUSTED

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BY: B. Morris DATE: 20 Sept 82 CHECKED BY: ______ DATE CHECKED: ______ 19 __

AND THE CALCULATIONS REPEATED. ONCE THE CALCULATED AND DESIRED DEFLECTIONS DIFFER BY LESS THAN 1%, THE REQUIRED STEEL AREA AND OTHER INPUT AND SECTION PROPERTIES ARE OUTPUT BY THE CODE.

THE PROGRAM USED FOR THE TWO-WAY SLAB DESIGN IS SIMILAR TO THAT DISCUSSED ABOVE.

THE NEXT PAGE INCLUDE A SUMMARY OF CONCRETE PROPERTIES USED IN THE ANALYSIS.

THE DESIGN METHODOLOGY FOR BLAST DOOR DESIGN IS BASED ON METHODS DESCRIBED IN REF [3]. THE BLAS DOOR DESIGN CALCULATIONS ARE SELF EXPLANITORY AS ATTACHED. REFERENCE THE CALCULATIONS SHEETS FOR A DISCUSSION OF METHODS USED.

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PROJECT NO.: 02-7092 SPONSOR: CERL
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BY: M WHITNEY DATE: 29 Sept 1982 CHECKED BY: ________ DATE CHECKED: ____ 19__

SUMMARY OF MATERIAL PROPERTIES:

CONCRETE:

$f'_c = 4000$ psi , $E_c = 3.62 \times 10^6$ psi

REINFORCING STEEL:

$f_y = 60{,}000$ psi , $f_u = 90{,}000$ psi , $E_s = 30 \times 10^6$ psi

FOR SUPPORT ROTATION $0° < \theta < 2°$

STATIC DESIGN STRESS , $f_s = f_y = 60{,}000$ psi

FOR SUPPORT ROTATION $2° < \theta < 5°$

STATIC DESIGN STRESS , $f_s = f_y + \frac{1}{4}(f_u - f_y)$

$f_s = 60 + \frac{1}{4}(90 - 60)$

$f_s = 67{,}500$ psi

FOR SUPPORT ROTATION $\theta > 5°$

STATIC DESIGN STRESS , $f_s = \frac{1}{2}(f_u + f_y)$

$f_s = \frac{1}{2}(60 + 90) = 75{,}000$ psi

DYNAMIC INCREASE FACTOR (DIF) = 1.2

$f_{dy} = (DIF)\, f_s$

FOR $0 < \theta < 2°$, $f_{dy} = 1.2(60{,}000) = 72{,}000$ psi

FOR $2° < \theta < 5°$, $f_{dy} = 1.2(67{,}500) = 81{,}000$ psi

FOR $5° < \theta$, $f_{dy} = 1.2(75{,}000) = 90{,}000$ psi

3. EXTERIOR SHELL STRUCTURAL DESIGN FOR AIRCRAFT IMPACT

THE ANALYSIS DETAILS WHICH FOLLOW WERE PRODUCED USING A NUMBER OF IN-HOUSE DEVELOPED COMPUTER CODES DESIGNED TO NUMERICALLY INTEGRATE THE EQUATIONS OF MOTION SUGGESTED IN BIGGS' INTRODUCTION TO STRUCTURAL DYNAMICS OR TO PERFORM OTHER MATHEMATICAL COMPUTATIONS. CODES USED ARE DESCRIBED BELOW:

'BEAMDES' — ITERATIVE DESIGN OF REINFORCED CONCRETE ONE WAY SLABS OR BEAMS SUBJECTED TO TIME-VARYING PRESSURE LOADS. IT USES BIGGS' SINGLE-DEGREE-OF-FREEDOM MODEL WITH STRUCTURAL PARAMETERS AS CALCULATED BY BIGGS OR TM5-1300.

'SLABDES' — SIMILAR TO ABOVE BUT FOR TWO-WAY REINFORCED CONCRETE SLABS.

'ARCH' — CALCULATES REACTIONS FOR FIXED-END ARCHES BASED ON ARCH SPAN, THICKNESS, AND RISE. GOVERNING EQUATIONS ARE FOUND IN FORMULAS FOR STRESS AND STRAIN BY ROARK AND YOUNG.

5-32

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COMPUTATION SHEET

SHEET NO. 18 OF 19

PROJECT NO.: 02-7032 SPONSOR: CERL
SUBJECT: EXTERIOR SHELL DESIGNS
BY: ______ DATE: ______ 19 ______ CHECKED BY: D. [illegible] DATE CHECKED: 25 SEPT 19 86

'ONEDF' — SINGLE-DEGREE-OF-FREEDOM MAXIMUM RESPONSE OF AN UNDAMPED MASS-SPRING SYSTEM TO A SPECIFIED TIME-VARYING LOAD. EQUATIONS OF MOTION ARE FROM BIGGS.

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COMPUTATION SHEET

SHEET NO. 19 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXTERIOR SHELL DESIGN
BY: DATE: 19 CHECKED BY: D KETCHUM DATE CHECKED: 25 SEPT 82

REFERENCES

(1) DOE/TIC-11268, "A MANUAL FOR PREDICTION OF BLAST AND FRAGMENT LOADINGS ON STRUCTURES," DEPARTMENT OF ENERGY, AMARILLO AREA OFFICE, PANTEX PLANT, NOVEMBER, 1980.

(2) TM5-1300, "STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS," DEPT OF THE ARMY TECH. MANUAL TM5-1300. DEPT. OF THE NAVY PUBLICATION NAVFAC P-397, DEPARTMENT OF THE AIR FORCE MANUAL AFM 88-22, JUNE 1969.

(3) "Suppressive Shields Structural Design and Analysis Handbook." HNDM-1110-1-2, U.S. Army Corps of Engineers, Huntsville Division, 18 Nov 1977.

(4) Biggs, J.M. Introduction to Structural Dynamics, McGraw-Hill Book Co., New York, New York, 1964.

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

III BLAST ANALYSIS

The following pages include interior blast load calculations for the 4 munitions storage bay designs and a typical maintenance bay design. The blast analysis was made using methods described in DOE/TIC-11268. The blast analysis is organized as follows:

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 2 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

1. Summary

Table 1 - Summary of Internal Loads

Bay Description	P (psi)	i (psi-sec)	t_d (sec)	P_{as} (psi)
Long Bay Design				
wall A	3673	0.68	0.00037	20
wall B	4078	0.72	0.00035	
wall C	79	0.25	0.0063	
dividing wall	4078	0.72	0.00035	
ceiling	833	0.42	0.001	
door	100	0.23	0.0046	
Pts Bay Design				
wall A	1500	0.51	0.00068	17
wall B	3200	0.58	0.00036	
dividing wall	12,250	1.14	0.00019	
ceiling	125	0.25	0.0039	
door	75	0.28	0.0032	
Maze Bay Design				
wall A	1930	0.56	0.00061	19
wall B	2170	0.44	0.00040	
dividing wall	12,250	1.14	0.00019	
ceiling	200	0.28	0.0027	
door	470	0.35	0.0015	
Double-Stacked Bay				
wall A	2632	0.53	0.0004	28
wall B	5780	0.95	0.00033	
wall C	69	0.23	0.0068	
dividing wall	5750	0.95	0.00033	
ceiling	780	0.30	0.00077	
door	100	0.23	0.0046	
Maintenance Bay				
wall	2770	0.42	0.00030	37
ceiling	238	0.32	0.0027	
door	17,249	1.19	0.00014	

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SHEET NO. 3 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sept 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

2 Internal Blast Loading

The following pages include calculations of shock and quasi-static loads determined using methods described in Section II.

2.1 Shock Loading

Shock loads were calculated in each of the four storage bays for the 9.7 ft × 3.1 ft × 3.3 ft munition should there be a detonation. Shock loads were also calculated for a typical maintenance bay. By sponsor instruction, no transport scenarios were analyzed. The worst case shock pressure, impulse and duration are summarized in Table 1 of Section I. The charge weight of 78.5 lb_{TNT} is increased by a factor of 1.2 as specified in TM5-1300. When the charge is considered as located on the floor, the charge weight is doubled for use with air blast curves.

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COMPUTATION SHEET

SHEET NO. 4 OF 47

PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: WRS DATE: 21 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

2.1.1 Shock Loadings for Long Bay

Summary of Blast Loads - Long Bay

Component	P (psi)	i (psi-sec)	t_d (sec)
wall A	3673	0.68	0.00037
wall B	4078	0.72	0.00035
wall C	79	0.25	0.0063
dividing wall	4078	0.72	0.00035
ceiling	833	0.42	0.001
door	100	0.23	0.0046

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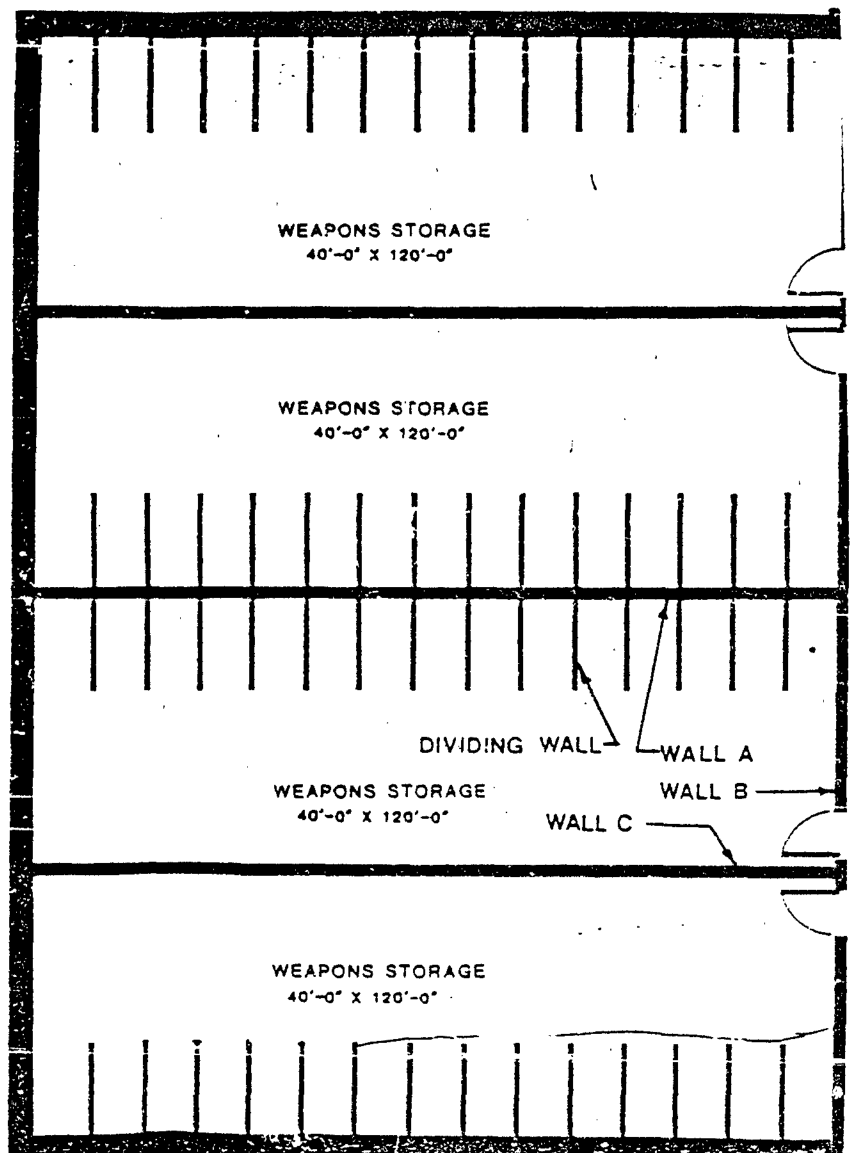
COMPUTATION SHEET

SHEET NO. 5 OF 7

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Floor plan - Long Bay Concept No. 4
BY: DEL DATE: 24 Sept 82 CHECKED BY: NPS DATE CHECKED: 24 Sep 19 82



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COMPUTATION SHEET

SHEET NO. 6 of 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ______ D. ______ ECKED: ______ 19 ______

WALL A - Long Bay

INPUT PARAMETERS.

CHARGE WEIGHT =	188.40 LB
PERPENDICULAR STANDOFF =	7.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	12.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC =	3.50 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC =	0.00 FT

OUTPUT:

AVERAGE PRESSURE = 0.2099E+04 PSI

TOTAL FORCE ON WALL = 0.2539E+08 LB
TOTAL APPLIED IMPULSE = 0.4694E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.39 PSI-SEC

$P_{avg} = 2099 \times 1.75 = \underline{3673 \text{ psi}}$

$i_{AVG} = 0.39 \times 1.75 = \underline{0.68 \text{ psi-sec}}$

$t_A = \frac{2i}{P} = \frac{2(.68)}{3673} = \underline{0.00037 \text{ sec}}$

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

WALL B + dividing wall - Long Bay

INPUT PARAMETERS:

CHARGE WEIGHT = 198.40 LB
PERPENDICULAR STANDOFF = 3.50 FT
PLATE LENGTH, XTOT = 12.00 FT
PLATE WIDTH, YTOT = 12.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER
LEFT PLATE CORNER, XC = 6.00 FT
WIDTHWISE DISTANCE FROM LOWER
LEFT PLATE CORNER, YC = 0.00 FT

OUTPUT:

AVERAGE PRESSURE = 0.2330E+04 PSI

TOTAL FORCE ON WALL = 0.4830E+08 LB
TOTAL APPLIED IMPULSE = 0.8576E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.41 PSI-SEC

P_{avg} = 2330 × 1.75 = 4078 psi

i_{avg} = .41 × 1.75 = 0.72 psi-sec

$t = \frac{2(.72)}{4078}$ = 0.00035 sec

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SHEET NO. 2 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

WALL C - Long Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	188.40 LB
PERPENDICULAR STANDOFF =	33.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	13.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC =	3.50 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC =	0.00 FT

OUTPUT:

AVERAGE PRESSURE = 0.4500E+02 PSI

TOTAL FORCE ON WALL = 0.5897E+06 LB
TOTAL APPLIED IMPULSE = 0.1795E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.14 PSI-SEC

$p_{avg} = 45 \times 1.75 = \underline{79\ psi}$

$i_{avg} = .14 \times 1.75 = \underline{0.25\ psi\text{-}sec}$

$t_d = \frac{2i}{p} = \frac{2(.25)}{79} = \underline{0.0063\ sec}$

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SHEET NO. 9 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

CEILING - Long Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	188.40 LB
PERPENDICULAR STANDOFF =	12.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	40.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC =	3.50 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC =	7.00 FT

OUTPUT:

AVERAGE PRESSURE = 0.476E+03 PSI

TOTAL FORCE ON WALL = 0.1920E+09 LB
TOTAL APPLIED IMPULSE = 0.9602E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.24 PSI-SEC

$P_{avg} = 476 \times 1.75 = \underline{833 \text{ psi}}$

$i_{avg} = 0.24 \times 1.75 = \underline{0.42 \text{ psi-sec}}$

$t_d = \frac{2i}{P} = \frac{2(.42)}{833} = \underline{0.0010 \text{ Sec}}$

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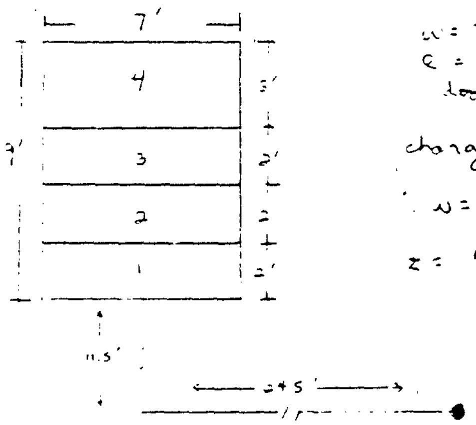
SHEET NO. 10 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 3 Aug 19 82 CHECKED BY: TKM DATE CHECKED: 17 Aug 19 82

Find the average pressure on the 7' × 9' door of the Long Bay Design for a charge located on the floor (assuming no dividing wall); charge is placed 24.5 ft horizontally from center of door



$w = 78.5$ lb

$R = 11.5$ ft (worst case impulse on door occurred for 2nd stall)

charge wt $= w \times 1.2 \times 2$ on floor

$\therefore w = 188.4$ lb and

$z = R/w^{1/3} = 2.0$ ft/lb$^{1/3}$

For each wall element shown, tabulate x/R, A and P_r

Element	x (ft)	x/R	A (ft²)	P (psi)	P·A (psi·ft²)
1	24.5	2.1	14	80	1120
2	24.7	2.1	14	80	1120
3	25.0	2.2	14	40	560
4	25.6	2.2	21	40	840
			$\Sigma = 63$ ft²		$\Sigma = 3640$ psi·ft²

$$\bar{P} = \frac{3640}{63} = 58 \text{ psi} \times 1.75 = \underline{\underline{100 \text{ psi}}}$$

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NES DATE: 30 Sep 1982 CHECKED BY: DATE CHECKED: 19

7X9 DOOR - Long Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	188.40 LB
PERPENDICULAR STANDOFF =	11.50 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	9.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM PLATE CORNER, XC =	28.00 FT
WIDTHWISE DISTANCE FROM PLATE CORNER, YC =	0.00 FT

OUTPUT:

TOTAL APPLIED IMPULSE = 0.1176E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.13 PSI-SEC

$i_{avg} = .13 \times 1.75 = 0.23$ psi-sec

$t_d = 2i/P = \frac{2(.23)}{100} = 0.0046$ sec

2.1.2 Shock Loadings for Pits Bay Design

Summary of Blast Loads – Pits			
Component	P (psi)	i (psi-sec)	t_d (sec)
wall A	1500	0.51	0.00068
wall B	3200	0.58	0.00036
ceiling	125	0.25	0.0039
dividing wall	12,250	1.14	0.00019
door	175	0.28	0.0032

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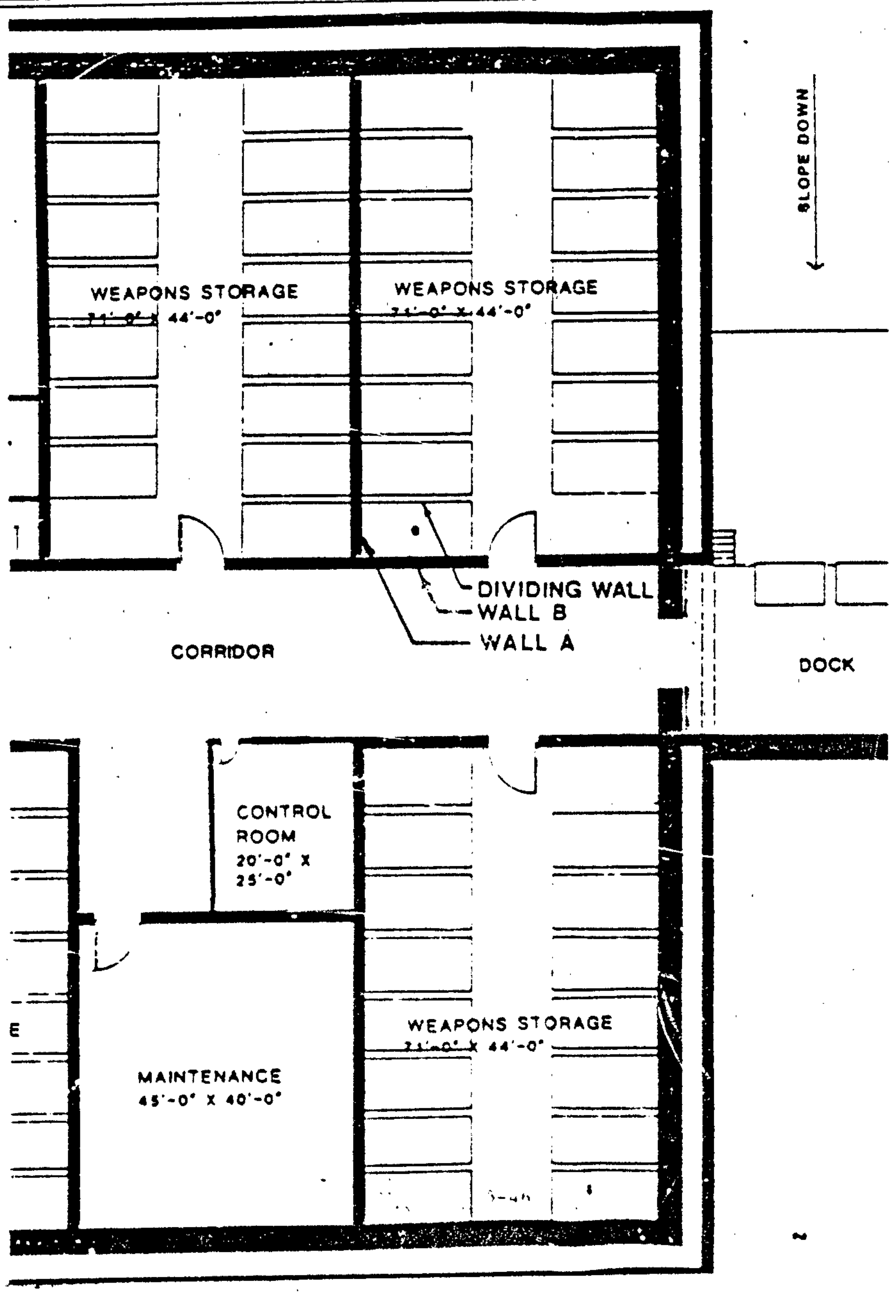
COMPUTATION SHEET

SHEET NO. 13 OF 47

PROJECT NO.: 02-7091 SPONSOR: CERL
SUBJECT: Floor Plan - Pits - Concept No. 2
BY: DEK DATE: 24 Sept 19 82 CHECKED BY: NRS DATE CHECKED: 24 Sep 19 82



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COMPUTATION SHEET

SHEET NO. 14 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

WALL A - Pits Bay

```
INPUT PARAMETERS

  CHARGE WEIGHT =                        189.40 LB
  PERPENDICULAR STANDOFF =                 8.50 FT
  PLATE LENGTH, XTOT =                     8.00 FT
  PLATE WIDTH, YTOT =                     25.00 FT

  CHARGE POSITION IN PLANE PARALLEL TO PLATE

  LENGTHWISE DISTANCE FROM LOWER
          LEFT PLATE CORNER, XC =      4.00 FT
  WIDTHWISE DISTANCE FROM LOWER
          LEFT PLATE CORNER, YC =      0.00 FT

OUTPUT

  AVERAGE PRESSURE =        0.8574E+03 PSI

  TOTAL FORCE ON WALL =        0.2469E+08 LB
  TOTAL APPLIED IMPULSE =        0.8292E+04  LB-SEC

  AVERAGE SPECIFIC IMPULSE =   0.29 PSI-SEC
```

[illegible]

[illegible]

[illegible]

WALL B - Pits Cay

INPUT PARAMETERS:

```
  CHARGE WEIGHT =                          198.40 LB
  PERPENDICULAR STANDOFF =                   4.00 FT
  PLATE LENGTH, XTOT =                      17.00 FT
  PLATE WIDTH, YTOT =                       25.00 FT

  CHARGE POSITION IN PLANE PARALLEL TO PLATE

  LENGTHWISE DISTANCE FROM LOWER
         LEFT PLATE CORNER, XC =     8.50 FT
  WIDTHWISE DISTANCE FROM LOWER
         LEFT PLATE CORNER, YC =    12.50 FT
```

OUTPUT

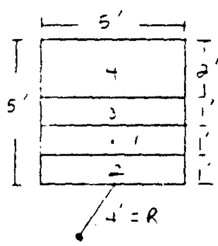
```
  AVERAGE PRESSURE =        0.1827E+04 PSI

  TOTAL FORCE ON WALL =       0.1116E+09 LB
  TOTAL APPLIED IMPULSE =       0.2046E+05  LB-SEC

  AVERAGE SPECIFIC IMPULSE =    0.33 PSI-SEC
```

P_{ave} = 3197 psi

i_s = [illegible] psi-sec

t_d = 3.6 × 10^-4 sec

Find the average peak pressure on a dividing wall of Pits Bay for a charge located in the air



$w = 78.5$ lb
$R = 4.0$ ft

charge wt = $w \times 1.2$ in air

$\therefore$ $w = 94.2$ lb and

$Z = R/w^{1/3} = 0.88$ ft/lb$^{1/3}$

For each wall element shown tabulate x/R, A, and i_r

Element	x(ft)	x/R	A (ft²)	$\bar{P}$ (psi)	PA (psi·ft²)
1	0	—	5	9000*	45000
2	1	0.25	5	8000	40000
3	1	0.25	5	8000	40000
4	2.5	0.63	10	5000	50000
			$\Sigma = 25$ ft²		$\Sigma = 175000$ psi ft²

* @ x/R = 0, Fig 2 was used

$$P = \frac{175000}{25} = 7000 \text{ psi} \times 1.75 = \underline{\underline{12,250 \text{ psi}}}$$

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: DATE CHECKED: 19

DIVIDING WALL - Fits Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	94.20 LB
PERPENDICULAR STANDOFF =	4.00 FT
PLATE LENGTH, XTOT =	5.00 FT
PLATE WIDTH, YTOT =	5.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM PLATE CORNER, XC =	2.50 FT
WIDTHWISE DISTANCE FROM PLATE CORNER, YC =	1.50 FT

OUTPUT:

TOTAL APPLIED IMPULSE = 0.2344E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.65 PSI-SEC

$$i = 1.75(.65) = \underline{\underline{1.14 \text{ psi-sec}}}$$

$$t_d = \frac{2i}{P} = \frac{2(1.14)}{12250} = \underline{\underline{0.00019 \text{ sec}}}$$

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SHEET NO. 18 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: DEK DATE CHECKED: 30 Sep 19 82

CEILING - Pits Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	198.40 LB
PERPENDICULAR STANDOFF =	25.00 FT
PLATE LENGTH, XTOT =	8.00 FT
PLATE WIDTH, YTOT =	44.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC = 4.00 FT

WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC = 35.50 FT

OUTPUT:

AVERAGE PRESSURE = 0.7148E+02 PSI

TOTAL FORCE ON WALL = 0.3622E+07 LB

TOTAL APPLIED IMPULSE = 0.7264E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.14 PSI-SEC

$P_{max} = 35$ psi

$i_{max} = .245$ psi-sec

$t_d = 3.9 \times 10^{-3}$ sec

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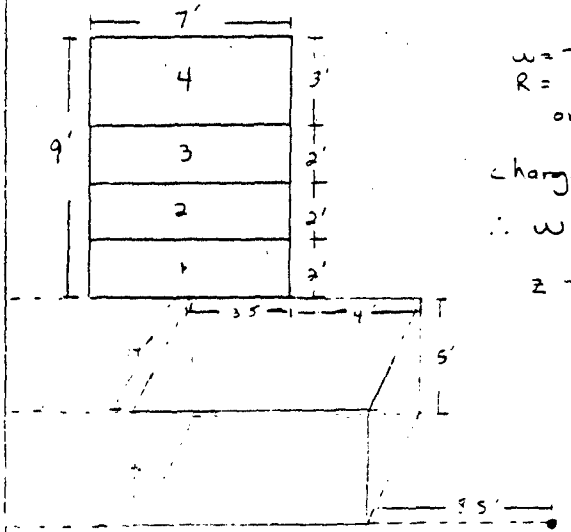
COMPUTATION SHEET

SHEET NO. 19 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 13 Aug 19 82 CHECKED BY: TKM DATE CHECKED: 19 Aug 19 82

Find the average peak pressure on the 7'x9' door of Pits Bay design for a charge located on the floor (assuming no dividing wall)



$w = 78.5$ lb
$R = 14$ ft (worst case impulse on door occured for 2nd stall)

charge wt = $w \times 1.2 \times 2$ on floor

$\therefore w = 188.4$ lb and

$z = R/w^{1/3} = 2.4$ ft/lb$^{1/3}$

For each wall element shown, tabulate x/R, A and P_r

Element	x (ft)	x/R	A (ft²)	P (psi)	PA (psi ft²)
1	22.1	1.58	14	120	1680
2	22.7	1.62	14	110	1540
3	23.5	1.68	14	100	1400
4	24.7	1.76	21	80	1680

$\Sigma = 63$ ft² $\Sigma = 6300$ psi ft²

$$P = \frac{6300}{63} = 100 \text{ psi} \times 1.75 = \underline{175 \text{ psi}}$$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 20 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: DATE CHECKED: 19

7X9 DOOR - F + S Bay

INPUT PARAMETERS:

CHARGE WEIGHT = 188.40 LB
PERPENDICULAR STANDOFF = 14.00 FT
PLATE LENGTH, XTOT = 7.00 FT
PLATE WIDTH, YTOT = 9.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM
PLATE CORNER, XC = 19.50 FT
WIDTHWISE DISTANCE FROM
PLATE CORNER, YC = -5.00 FT

OUTPUT:

TOTAL APPLIED IMPULSE = 0.1442E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.16 PSI-SEC

$i = 1.75\,(.16) = \underline{0.28\text{ psi-sec}}$

$t_d = \frac{2i}{P} = \frac{2(.28)}{175} = \underline{0.0032\text{ sec}}$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 21 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 22 Sep 19 82 CHECKED BY: DATE CHECKED: 19

2.1.3 Shock Loading for Maze Bay Design

Summary of Blast Loads - Maze			
Component	P(psi)	i(psi-sec)	t_d (sec)
Wall A	1830	0.56	0.00061
Wall B	2170	0.44	0.00040
dividing wall	12,250	1.14	0.00019
ceiling	200	0.28	0.0027
door	470	0.35	0.0015

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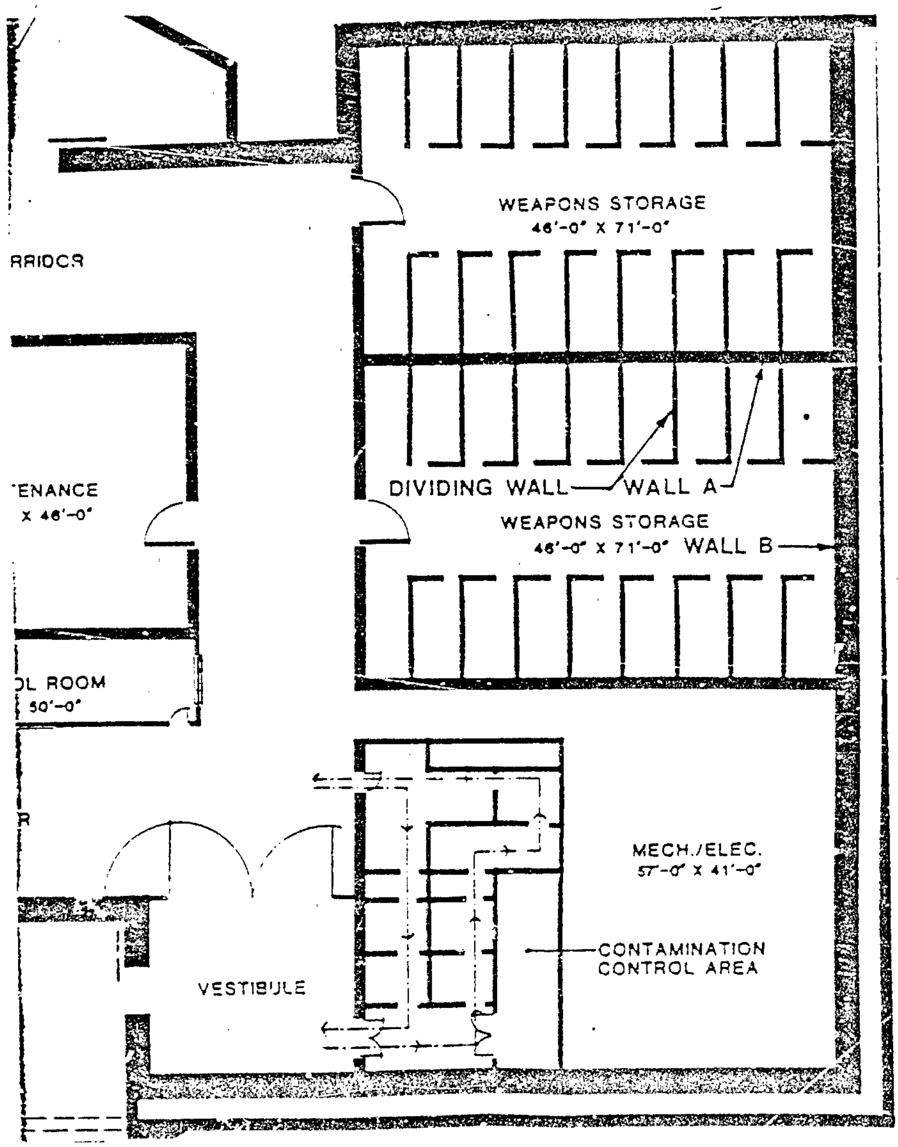
COMPUTATION SHEET

SHEET NO. 22 OF 47

PROJECT NO: 02-7092 SPONSOR: CERL
SUBJECT: Floor Plan of [illegible] Concept - No. 5
BY: [illegible] DATE: 24 Sept 19 82 CHECKED BY: NRS DATE CHECKED: 24 Sep 19 82



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COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: DEK DATE CHECKED: 30 Sep 19 82

WALL A – Maze Bay

INPUT PARAMETERS:

```
  CHARGE WEIGHT =                      188.40 LB
  PERPENDICULAR STANDOFF =               8.50 FT
  PLATE LENGTH, XTOT =                   8.00 FT
  PLATE WIDTH, YTOT =                   20.00 FT

  CHARGE POSITION IN PLANE PARALLEL TO PLATE

  LENGTHWISE DISTANCE FROM LOWER
         LEFT PLATE CORNER, XC =    4.00 FT
  WIDTHWISE DISTANCE FROM LOWER
         LEFT PLATE CORNER, YC =    0.00 FT

OUTPUT:

  AVERAGE PRESSURE =       0.1046E+04 PSI

  TOTAL FORCE ON WALL =       0.2410E+08 LB
  TOTAL APPLIED IMPULSE =      0.7431E+04  LB-SEC

  AVERAGE SPECIFIC IMPULSE =   0.32 PSI-SEC
```

P_{ave} = 1833.5 psi

i_{ave} = .56 psi-sec

t_d = 6.1 x 10^{-4} sec

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COMPUTATION SHEET

SHEET NO 27 OF 37

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 22 Sep 19 82 CHECKED BY: DEK DATE CHECKED: 30 Sep 19 82

WALL B - Maze Bay

INPUT PARAMETERS

CHARGE WEIGHT =	188 40 LB
PERPENDICULAR STANDOFF =	4 00 FT
PLATE LENGTH, XTOT =	17 00 FT
PLATE WIDTH, YTOT =	20 00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER XC =	8 50 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER. YC =	0 00 FT

OUTPUT

AVERAGE PRESSURE = 0 1237E+04 PSI

TOTAL FORCE ON WALL = 0 6057E+06 LB
TOTAL APPLIED IMPULSE = 0 1231E+05 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0 25 PSI-SEC

P_{avg} = 2 ,5 Psi
[illegible] = .44 psi-sec
t_d = [illegible] sec

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COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NKS DATE: 22 Sep 19 82 CHECKED BY ______ DATE CHECKED ______ 19 ___

Dividing Wall - Maze Bay Design

The shock pressure, impulse and duration on the dividing wall of the maze bay are the same as that calculated for the dividing wall of the pits bay design (see Sec 2.1.2)

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COMPUTATION SHEET

SHEET NO. 26 OF 47

PROJECT NO. 02-7032 SPONSOR CERL
SUBJECT Blast Analysis
BY SSS DATE 30 Sep 19 82 CHECKED BY DEK DATE CHECKED 30 Sep 19 82

CEILING – Main Bay

INPUT PARAMETERS

```
CHARGE WEIGHT =                       188 50 LB
PERPENDICULAR STANDOFF =               20 00 FT
PLATE LENGTH, XTOT =                    8 00 FT
PLATE WIDTH, YTOT =                    46 00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER
      LEFT PLATE CORNER, XC =       4 00 FT
WIDTHWISE DISTANCE FROM LOWER
      LEFT PLATE CORNER, YC =      37 50 FT
```

OUTPUT

```
AVERAGE PRESSURE =        0 1187E+03 PSI

TOTAL FORCE ON WALL =        0 6290E+07 LB
TOTAL APPLIED IMPULSE =        0 9691E+[illegible]  LB-SEC

AVERAGE SPECIFIC IMPULSE =    0 16 PSI-SEC
```

P_{ave} [illegible]
i_{ave} [illegible]
t_d [illegible]

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COMPUTATION SHEET

SHEET NO. 27 OF 47

PROJECT NO.: 02-7012 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 20 Sep 1982 CHECKED BY: DEK DATE CHECKED: 30 Sep 1982

DOOR - maze bay

INPUT PARAMETERS

CHARGE WEIGHT = 188.40 LB
PERPENDICULAR STANDOFF = 13.00 FT
PLATE LENGTH, XTOT = 7.00 FT
PLATE WIDTH, YTOT = 9.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER
LEFT PLATE CORNER, XC = -10.00 FT
WIDTHWISE DISTANCE FROM LOWER
LEFT PLATE CORNER, YC = 0.00 FT

OUTPUT

AVERAGE PRESSURE = 0.2677E+03 PSI

TOTAL FORCE ON WALL = 0.2429E+07 LB
TOTAL APPLIED IMPULSE = 0.1790E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.20 PSI-SEC

P_{ave} = 408.5 psi

i_{ave} = .35 psi-sec

t_d = 5×10^{-3} sec

2.1.4 Double-Stacked Bay Design

Summary of Blast Loads - Double stacked

component	P (psi)	i (psi-sec)	T_d (sec)
wall A	2632	0.53	0.0004
wall B	5730	0.95	0.00033
wall C	68	0.23	0.0068
dividing wall	5730	0.95	0.00033
ceiling	780	0.30	0.00077
door	100	0.23	0.0046

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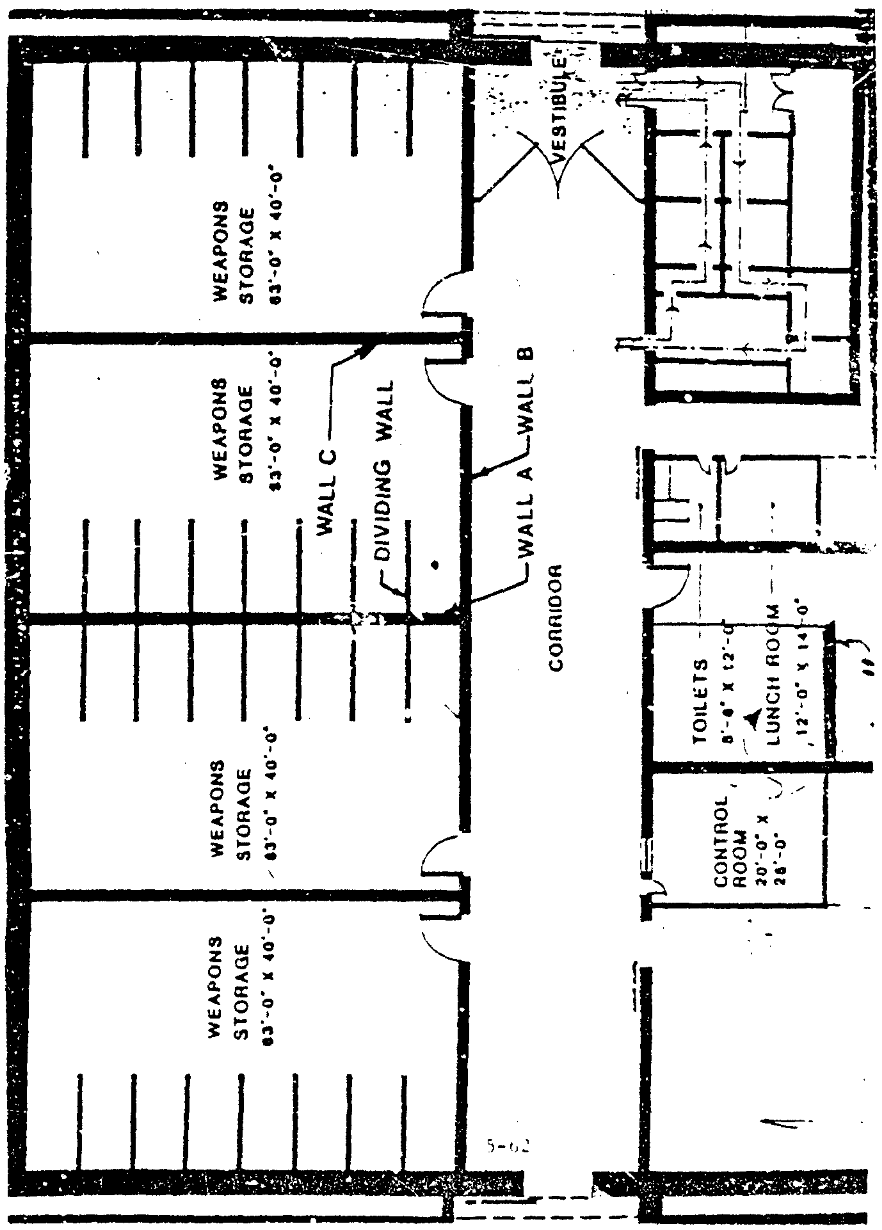
COMPUTATION SHEET

SHEET NO. 27 OF 47

PROJECT NO.: 02-7292 SPONSOR: CERL
SUBJECT: Floor Plan - Double Stacked - Concept No. 1
BY: DEK DATE: 23 Sep 1982 CHECKED BY: NRS DATE CHECKED: 24 Sep 1982



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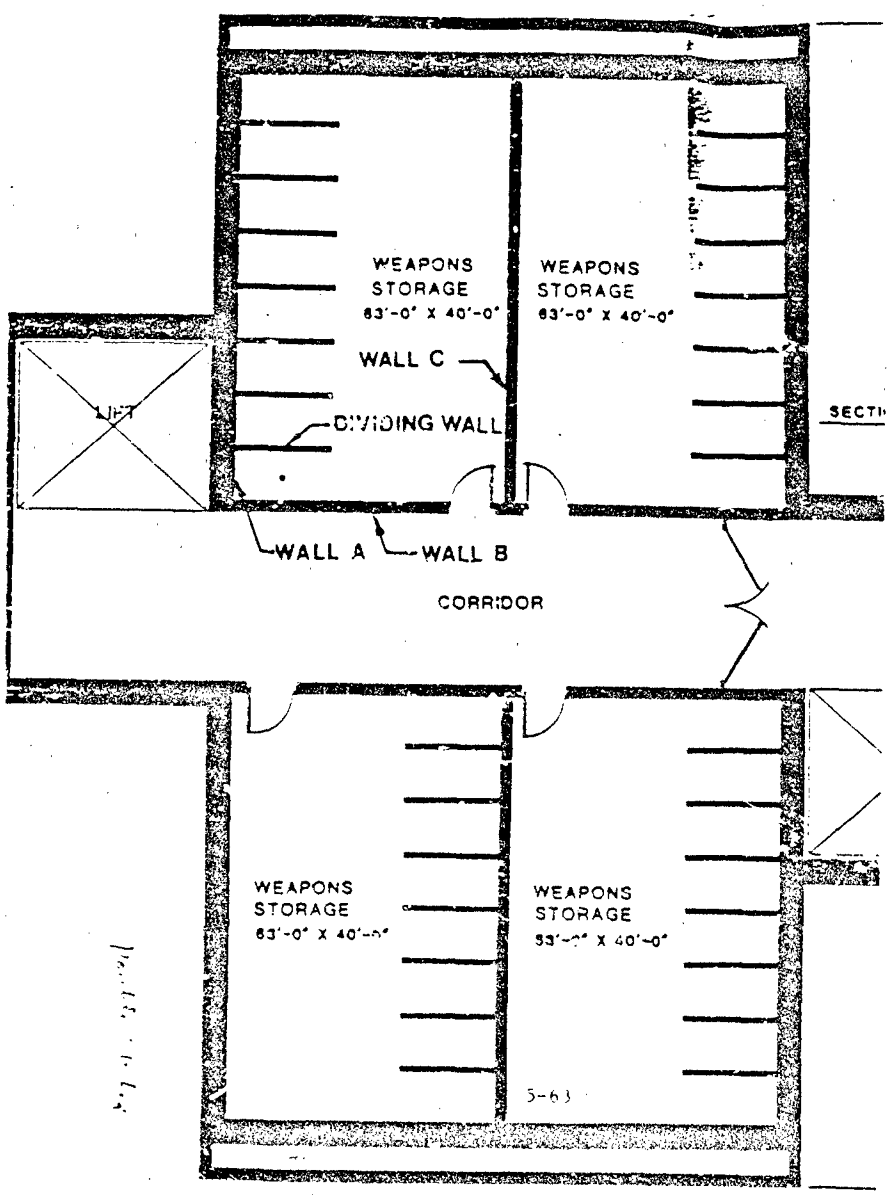
COMPUTATION SHEET

SHEET NO. 30 OF 47

PROJECT NO.: 02-392 SPONSOR: CERL
SUBJECT: Floor Plan - Double Stacked Concept No. 3
BY: DEK DATE: 24 Sep 19 82 CHECKED BY: VKS DATE CHECKED: 24 Sep 19 82



PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

WALL A - Coupled-stacked Cay

INPUT PARAMETERS

CHARGE WEIGHT =	188.40 LB
PERPENDICULAR STANDOFF =	7.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	18.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC =	3.50 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC =	0.00 FT

OUTPUT

AVERAGE PRESSURE = 0.1504E+04 PSI

TOTAL FORCE ON WALL = 0.2723E+08 LB
TOTAL APPLIED IMPULSE = 0.5475E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.30 PSI-SEC

$P_{avg} = 1504 \times 1.75 = \underline{2632 \text{ psi}}$

$i_{avg} = 0.30 \times 1.75 = \underline{0.53 \text{ psi-sec}}$

$t_d = 2i/P = \frac{2(.53)}{2632} = \underline{0.00040 \text{ sec}}$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO 32 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 30 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

WALL B and Dividing Wall - Double stacked

INPUT PARAMETERS

```
CHARGE WEIGHT =                          188.40 LB
PERPENDICULAR STANDOFF =                   3.50 FT
PLATE LENGTH, XTOT =                       8.00 FT
PLATE WIDTH, YTOT =                        8.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER
      LEFT PLATE CORNER, XC =         7.00 FT
WIDTHWISE DISTANCE FROM LOWER
      LEFT PLATE CORNER, YC =         0.00 FT
```

OUTPUT

```
AVERAGE PRESSURE =       0.3303E+04 PSI

TOTAL FORCE ON WALL =       0.3044E+08 LB
TOTAL APPLIED IMPULSE =      0.4982E+04  LB-SEC

AVERAGE SPECIFIC IMPULSE =    0.54 PSI-SEC
```

$P_{avg} = 3303 \times 1.75 = \underline{5780 \text{ psi}}$

$i_{avg} = 0.54 \times 1.75 = \underline{0.95 \text{ psi-sec}}$

$t_d = \frac{2i}{P} = \frac{2(.95)}{5780} = \underline{0.00033 \text{ sec}}$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 33 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 20 Sep 1983 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

WALL C - Double Stacked Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	198.40 LB
PERPENDICULAR STANDOFF =	33.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	19.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE:

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC =	7.00 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC =	0.00 FT

OUTPUT:

AVERAGE PRESSURE = 0.3913E+02 PSI

TOTAL FORCE ON WALL = 0.7100E+06 LB
TOTAL APPLIED IMPULSE = 0.2273E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.13 PSI-SEC

$P_{avg} = 39 \times 1.75 = \underline{68\ psi}$

$i_{avg} = 0.13 \times 1.75 = \underline{0.23\ psi\text{-}sec}$

$t_d = 2i/P = \frac{2(.23)}{68} = \underline{0.0068\ sec}$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 34 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 20 Sep 19 82 CHECKED BY: DEK DATE CHECKED: 30 Sept 19 82

CEILING - Double-Stacked Bay

INPUT PARAMETERS:

CHARGE WEIGHT =	94.20 LB
PERPENDICULAR STANDOFF =	9.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	40.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, XC =	3.50 FT
WIDTHWISE DISTANCE FROM LOWER LEFT PLATE CORNER, YC =	33.00 FT

OUTPUT:

AVERAGE PRESSURE = 0.4462E+03 PSI

TOTAL FORCE ON WALL = 0.1799E+08 LB
TOTAL APPLIED IMPULSE = 0.6998E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.17 PSI-SEC

P_{ave} = 782.5 psi

i_{ave} = .30 psi-sec

t_d = 7.7 x 10^{-4} sec

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 35 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 30 Sep 1982 CHECKED BY: DATE CHECKED: 19

Door - Double-stacked Bay Design

The shock pressure impulse and duration on the door of the Doubled stacked Bay are the same as that for the door of the Long Bay (see Sec. 2.1.1)

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COMPUTATION SHEET

SHEET NO. 36 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Revised Maintenance Bay
BY: NRS DATE: 22 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

2.1.5 Shock Loads for Maintenance Bay

Summary of Blast Loads - Maintenance Bay			
Component	P (psi)	i (psi-sec)	t_d (sec)
wall	2770	0.42	0.00030
roof	238	0.32	0.0027
door	17248	1.19	0.00014

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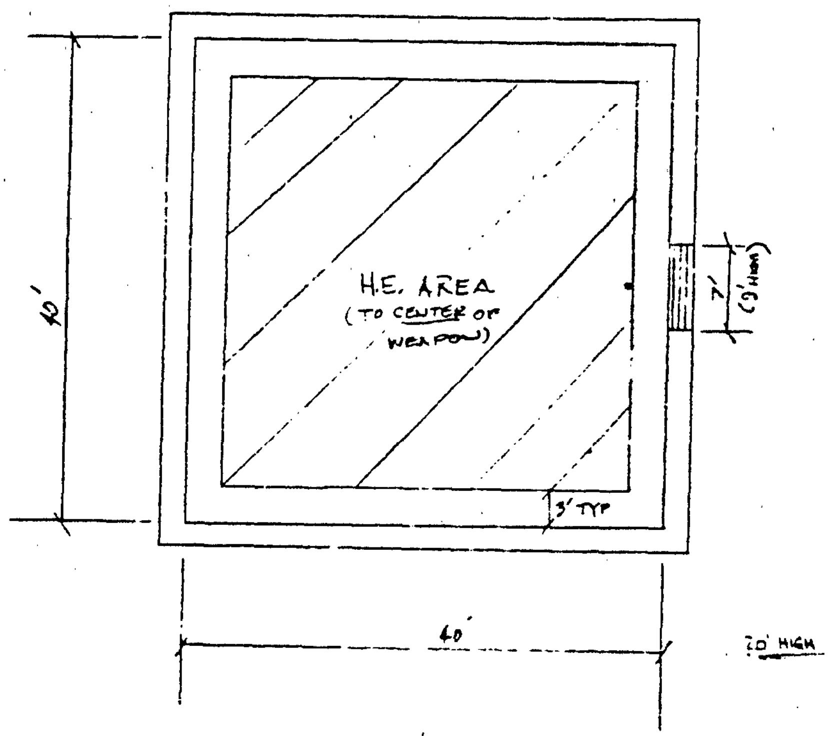
COMPUTATION SHEET

SHEET NO. 37 OF 77

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NRS DATE: 29 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___



MAINTENANCE BAY
Floor Plan

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COMPUTATION SHEET

SHEET NO. 38 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRS DATE: 30 Sep 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

WALL - Maintenance Bay

INPUT PARAMETERS

```
  CHARGE WEIGHT =                        188 40 LB
  PERPENDICULAR STANDOFF =                 3 00 FT
  PLATE LENGTH, XTOT =                    20 00 FT
  PLATE WIDTH, YTOT =                     20 00 FT

  CHARGE POSITION IN PLANE PARALLEL TO PLATE

  LENGTHWISE DISTANCE FROM LOWER
         LEFT PLATE CORNER, XC =     10 00 FT
  WIDTHWISE DISTANCE FROM LOWER
         LEFT PLATE CORNER, YC =      0 00 FT
```

OUTPUT

```
  AVERAGE PRESSURE =        0 1582E+04 PSI

  TOTAL FORCE ON WALL =        0 5126E+08 LB
  TOTAL APPLIED IMPULSE =        0 1383E+05  LB-SEC

  AVERAGE SPECIFIC IMPULSE =     0 24 PSI-SEC
```

$P_{avg} = 1582 \times 1.75 = \underline{2770\ psi}$

$i_{avg} = 0.24 \times 1.75 = \underline{0.42\ psi-sec}$

$t_d = 2i/p = \frac{2(.42)}{2770} = \underline{0.00030\ sec}$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 39 OF 47

PROJECT NO. 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: NES DATE: 30 Apr 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

ROOF - Maintenance Bay

INPUT PARAMETERS

CHARGE WEIGHT = 188.40 LB
PERPENDICULAR STANDOFF = 20.00 FT
PLATE LENGTH, XTOT = 20.00 FT
PLATE WIDTH, YTOT = 40.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM LOWER
LEFT PLATE CORNER, XC = 10.00 FT
WIDTHWISE DISTANCE FROM LOWER
LEFT PLATE CORNER, YC = 20.00 FT

OUTPUT

AVERAGE PRESSURE = 0.1364E+03 PSI

TOTAL FORCE ON WALL = 0.1572E+08 LB
TOTAL APPLIED IMPULSE = 0.2070E+05 LB-SEC

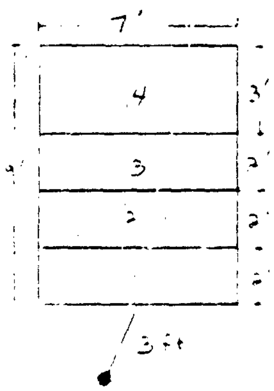
AVERAGE SPECIFIC IMPULSE = 0.18 PSI-SEC

$P_{avg} = 136 \times 1.75 = \underline{238 \text{ psi}}$

$i_{avg} = 0.18 \times 1.75 = \underline{0.32 \text{ psi-sec}}$

$t_d = \frac{2i}{P} = \frac{2(.32)}{238} = \underline{0.0027 \text{ sec}}$

Find the average peak pressure on the 7'×9' door of the maintenance bay for a charge on the floor.



$w = 78.5$ lb

standoff to center of weapon, $R = 3$ ft

charge wt = $w \times 1.2 \times 2$ on floor

$w = 188.4$ lb and

$Z = R/w^{1/3} = 0.52$ ft/lb$^{1/3}$

Using Fig 2 for each element shown tabulate x/R, A and P_r.

Element	x (ft)	x/R	A (ft²)	P (psi)	PA (psi-ft²)
1	0	—	14	23500*	329000
2	3	1.0	14	14000	196000
3	5	1.7	14	4000	56000
4	7.5	2.5	21	1900	39900

*Fig 1 was used

$\Sigma = 63$ ft²

$\Sigma = 620900$ psi-ft²

$$P = \frac{620900}{63} = 9856 \times 1.75 = \underline{17248 \text{ psi}}$$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO 41 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Blast Analysis
BY: NRJ DATE: 30 Sep 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

MAINTENANCE BAY DOOR

INPUT PARAMETERS:

CHARGE WEIGHT =	188.40 LB
PERPENDICULAR STANDOFF =	3.00 FT
PLATE LENGTH, XTOT =	7.00 FT
PLATE WIDTH, YTOT =	9.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM PLATE CORNER, XC =	3.50 FT
WIDTHWISE DISTANCE FROM PLATE CORNER, YC =	0.00 FT

OUTPUT

TOTAL APPLIED IMPULSE = 0.6194E+04 LB-SEC

AVERAGE SPECIFIC IMPULSE = 0.68 PSI-SEC

$i = 1.75\,(.68) = \underline{\underline{1.19\ \text{psi-sec}}}$

$T = \frac{2i}{P} = \frac{2\,(\ \ )}{1.7245} = \underline{\underline{0.0014\ \text{sec}}}$

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COMPUTATION SHEET

SHEET NO. 42 OF 49

PROJECT NO. 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY LKS DATE 20 Sep 19 82 CHECKED BY: DATE CHECKED: 19

2.2 Quasi-static Loading

In this section, the quasi-static loadings on each of the 4 munition storage bays and the maintenance bay are calculated. Drawings of each design are included in Section 2.1 of this appendix.

Quasi-static Load Summary	
Bay	P_{QS} (psi)
Long Bay	20
Fits Bay	17
Maze Bay	19
Double-stacked Bay	38
Maintenance Bay	37

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO 43 OF 47

PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: LRS DATE: 21 Sep 1982 CHECKED BY: ________ DATE CHECKED: ______ 19 ___

2.2.1 Quasi-static Loading for Long Bay Design

To find the quasi-static pressure corresponding to the long bay design, first find volume to be considered.

119 ft × 40 ft × 13 ft = 61880 ft^3

Bay ceiling volume to subtract = 1666 ft^3

munition volume = 9.67 ft × 3.08 ft × 3.25 ft = 96.8 ft^3
96.8 ft^3 × 15 munitions = 1452 ft^3

Dividing wall volume = 140 ft^3 × 14 walls = 1960 ft^3

61880 ft^3 − 1666 ft^3 − 1452 ft^3 − 1960 ft^3 = 56802 ft^3

Volume to be considered = 56,802 ft^3

weight of explosive = 35.6 Kg = 78.5 lb × 1.2 = 94.2 lb

$$\frac{W}{V} = \frac{94.2 \text{ lb}}{56802 \text{ ft}^3} = 1.66 \times 10^{-3} \frac{\text{lb}}{\text{ft}^3}$$

using Figure 5, P_{QS} = 20 psi.

PROJECT NO. 02-7092 SPONSOR: CERL
SUBJECT: BLAST ANALYSIS
BY: LKS DATE 22 19 82 CHECKED BY: DATE CHECKED: 19

2.2.2 Quasi-static Loading for Pits Bay Design

To find the quasi-static pressure corresponding to the pits design first find the volume to be considered

$71\ ft \times 44\ ft \times 25\ ft = 78{,}100\ ft^3$

Munition volume $= 9.67\ ft \times 3.07\ ft \times 3.25\ ft = 96.5\ ft^3$

$96.5\ ft^3 \times 15$ munitions $= 1452\ ft^3$

Dividing Wall Volume =

$85\ ft^3 \times 14$ walls (1' walls) $= 1190\ ft^3$

$3550\ ft^3 \times 1$ wall (middle) $= \underline{3550\ ft^3}$

$4740\ ft^3$

$78{,}100\ ft^3 - 1452\ ft^3 - 4740\ ft^3 = 71{,}908\ ft^3$

Volume to be considered $= 71{,}908\ ft^3$

Weight of explosive $= 35.6\ Kg = 78.5\ lb \times 1.2 = 94.2\ lb$

$$\frac{W}{V} = \frac{94.2\ lb}{71{,}908\ ft^3} = 1.31 \times 10^{-3} \frac{lb}{ft^3}$$

Using Figure 5, $P_{QS} = \underline{\underline{17\ psi}}$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 45 OF 47

PROJECT NO.: [illegible] SPONSOR: [illegible]
SUBJECT: [illegible]
BY: [illegible] DATE [illegible] 19 [illegible] CHECKED BY: NRS DATE CHECKED: 23 Sep 82

2.2.3 Quasi-Static Pressures for the Maze Room

Considered Volume = Total Volume − Munitions Volume − Dividing Wall Vol.

$V = V_T - V_m - V_D$

$V_T = 46' \times 7[illegible] \times 20' = 65320\ ft^3$

$V_m = 1452\ ft^3$

V_D = 16 walls × 1' deep × (5' high) × (17 + 8' long) = 2000 ft^3

$V = 65320 - 1452 - 2000$

$= 61\ 868\ ft^3$

Charge weight (W) = 35.6 kg TNT

= 78.5 lb × 1.2 safety factor = 94.2 lb.

$\frac{W}{V} = \frac{94.2}{61\ 868} = 1.5 \times 10^{-3}\ lb/ft^3$

Using Figure 5 $\underline{P_{qs} = 19\ psi}$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 46 OF 47

PROJECT NO.: [illegible] SPONSOR: CERL
SUBJECT: [illegible]
BY: [illegible] DATE: [illegible] 19 82 CHECKED BY: NRS DATE CHECKED: 23 Sept 19 82

2.2.4 Quasi Static Pressures for the 'Double Stacked' Room

Considered Volume = Total Volume − Munition Volume − Dividing Wall Volume

$$V = V_T - V_m - V_D$$

$V_T = 40 \times 64 \times 18 = 46\ 080\ ft^3$

$V_m = 1452\ ft^3$

V_D = 8 walls × 14' long × 1' deep × 8' high
+ 1 floor × 14' wide × 64' long × 1' deep
+ 8 walls × 4' long × 8' high × 1' deep
= 2800 ft^3

$V = 46\ 080 - 1\ 452 - 2\ 800 = 41\ 828\ ft^3$

W = 35.6 kg/unit = 78.5 lb

78.5 lb × 1.2 = W = 94.2 lb

$$\frac{W}{V} = \frac{94.2}{41\ 828} = 2.25 \times 10^{-3}\ lb/ft^3$$

Using Figure 5, $\underline{\underline{P_{QS} = 28\ psi}}$

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COMPUTATION SHEET

SHEET NO. 47 OF 47

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT:
BY: NRS DATE: 22Feb 19 82 CHECKED BY: DATE CHECKED: 19

2.2.5 Quasi-static Loading for Typical Maintenance Bay

Find the quasi-static pressure occurring in the maintenance bay. Estimating the room volume occupied by equipment and machinery at 20% of the bay volume we find the volume to be considered.

Volume of bay = 40 ft × 40 ft × 20 ft = 32000 ft^3

$(32000\ ft^3)(.2) = 6400\ ft^3$ for equipment

Volume to be considered = $32000\ ft^3 - 6400\ ft^3 = 25{,}600\ ft^3$

weight of explosive = 35.6 Kg = 78.5 lb × 1.2 = 94.2 lb

$$\frac{W}{V} = \frac{94.2\ lb}{25{,}600\ ft^3} = 3.68 \times 10^{-3}\ \frac{lb}{ft^3}$$

Using Figure 5, P_{QS} = 37 psi

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: INTERIOR WALL DESIGN
BY: D KETCHUM DATE: 30 SEPT 19 82 CHECKED BY: DATE CHECKED: 19

INTERIOR WALL DESIGN

INTRODUCTION -

THE BLAST LOADINGS FROM THE DETONATION OF EXPLOSIVES WITHIN THE STRUCTURE GOVERN THE DESIGN OF THE INTERIOR WALLS. THE BLAST LOADINGS AND THE DIAGRAMS DESIGNATING WALLS AS A, B, OR C CAN BE FOUND IN THE BLAST LOADING SECTION OF THIS APPENDIX.

THE WALLS HAVE BEEN DESIGNED FOR AN ALLOWABLE ROTATION OF 1°. THE CALCULATIONS ARE PRESENTED WITH A SUMMARY OF DESIGN REQUIREMENT RESULTS, COMPUTER OUTPUT ESTIMATING THE STEEL AREA REQUIRED IN THE WALL, AND A WORKSHEET OF BAR SIZING CALCULATIONS.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 2 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: INTERIOR WALL DESIGN SUMMARY
BY: D. Kitchum DATE: 30 Sept 19 82 CHECKED BY: MLV DATE CHECKED: 30 Sept 19 82

INTERIOR WALL DESIGN SUMMARY

COMPART	WALL	Tc	FLEX	TEMP	LACING	A_s	REQUIRED A_s
LONG	A	24	7	6	5	.60	.51
BAY	B	24	9	6	5	1.0	.82
	C	24	7	6	5	.60	.51
	DIV.	12	5	4	5	.31	—
DOUBLE	A	24	7	6	5	.60	.51
STACKED	B	24	9	6	7	1.0	.84
	C	24	9	6	5	1.0	.87
	DIV	12	5	4	5	.31	—
MAINT.	·	24	(2) 9	6	7	2.0	1.70
BAY							
ATS	A	24	10	6	5	1.27	1.11
	B	24	10	6	5	1.27	1.25
	DIV	12	5	4	5	.31	—
MAZE	A	24	7	6	5	.60	.51
	B	24	10	6	5	1.27	1.04
	DIV.	12	5	4	5	.31	—

SPACING = 12"
LACING USES METHOD 2

LONG BAY WALL A

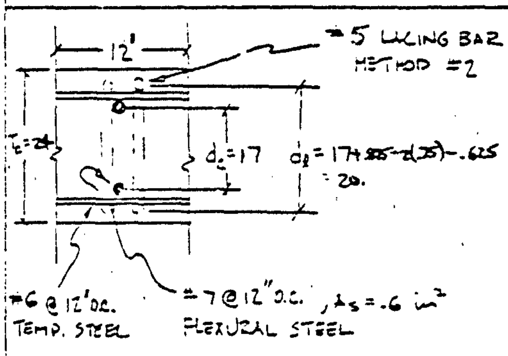
SUMMARY -

$T_c = 24"$
FLEXURAL BAR #7@12
TEMPERATURE BAR #6@5
LACING BAR #5 METHOD 2

COMPUTER OUTPUT -

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS    F1 =  .3100E+06     F2 =  .1680E+04
                   T2 =  .3700E-03     T4 =  .1000E+02

BEAM PARAMETERS    L =  144.00     THICK =   24.00
     D =  3.50     D' =  3.50
     ROTATION =  1.00      THATL =   .315E-02

FC' =    4000.     FDY =   72000.

IE =  .1152E+04     IC =  .5570E+02     IA =  .5043E+03
KEL =  .2826E+06     KELPL =  .5653E+05
 L1 =  .2721E+04       L2 =  .3628E+04

REQUIRED STEEL AREA =    .0267 SQ IN/IN =    .3201 SQ IN/FT
```

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 12\ FT = 144\ in$

$$M = \frac{A_s f_s d_c}{b}$$

$$M = \frac{.6\,(72000)\,17}{12} = 6.1\times10^4\ \frac{in\text{-}lb}{in}$$

$$r_u = \frac{16M}{L^2} = \frac{16\,(6.1\times10^4)}{(144)^2} = 47.2\ psi$$

FLEX. BAR, $A_s > .0025\ bd_c = .0025(12)(17) = .51\ in^2$
TEMP. BAR, $A_T > .0015\ bd_c = .0015(12)(17) = .31\ in^2$
$A_T =$ #6 BAR $= .44\ in^2 > A_{s/4}$

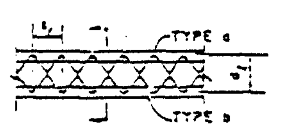
$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{47.2\left(\frac{144}{2} - 17\right)}{17} = 153\ psi$$

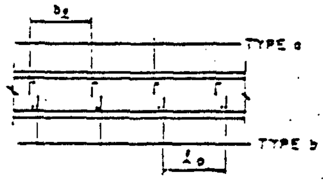
$$p = A_s/d_c b = \frac{.60}{(17)(12)} = .0029$$

$$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.0029)) = 108\ psi$$

$$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123\ psi$$

$V_c < V_u$ USE V_c $\therefore v_u' = 108 = 108$ psi





METHOD #2

$$s_\ell/d_\ell = \frac{12}{20.} = .6\ ,\quad \frac{TD_b}{d_\ell} = \frac{7(.625)}{20.} = .22$$

FROM FIG. 6-19 OF TM5, $\alpha = 67°$

$$A_T = \frac{v_u' S_\ell b_\ell}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{108(12)(12)}{.85(60000)(\sin 67 + \cos 67)}$$

$A_T = .23\ in^2$

USE #5 BAR

Long Bay Wall B

Summary -

$T_c = 24"$
Flex #9 @ 12
Temp #6 @ 12
Lacing #5 method 2

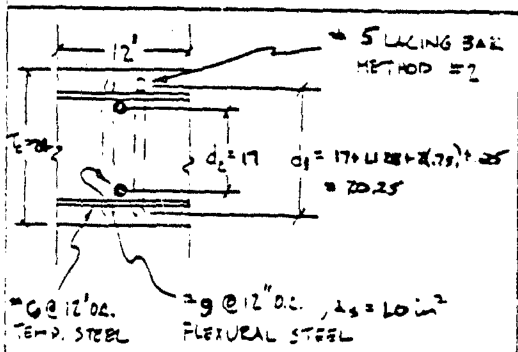
Computer output

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS   F1 =  .5872E+06     F2 =  .2880E+04
                  T2 =  .3500E-03     T4 =  .1000E+02

BEAM PARAMETERS   L =  144.00     THICK =   24.00
     D =  3.50      D' =  3.50
     ROTATION =  1.00      TNATL =   .891E-02

FC' =    4000.      FDY =   72000.

IE =  .1152E+04     IC =  .1202E+03     IA =  .5351E+03
KEL =  .2975E+06     KELPL =  .5950E+05
 L1 =  .6937E+04       L2 =  .9249E+04

REQUIRED STEEL AREA =    .0680 SQ IN/IN =    .8151 SQ IN/FT
```

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING/LONG BAY/WALL B
BY: D KETCHUM DATE: 23 Sept 19 82 CHECKED BY: ______ DATE CHECKED ______ 19 ____

LACING DESIGN



FIXED-FIXED SUPPORTS

$L = 12$ FT $= 144$ in

$$M = \frac{A_s f_s d_c}{b}$$

$$M = \frac{1.0\,(70000)\,17}{12} = 1.0 \times 10^5 \ \frac{in\text{-}lb}{in}$$

$$r_u = \frac{16M}{L^2} = \frac{16\,(1.0 \times 10^5)}{(144)^2} = 77\ psi$$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(17) = .51\ in^2$

TEMP BAR, $A_s > .0015\ b d_c = .0015(12)(17) = .31\ in^2$

$A_T = $ #6 BAR $= .44\ in^2 > A_s/2$

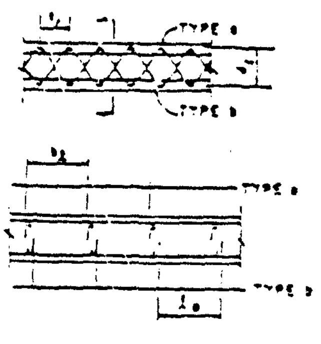
$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{77\left(\frac{144}{2} - 17\right)}{17} = 249\ psi$$

$$p = A_s / d_c b = \frac{1.0}{(17)(12)} = .005$$

$$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.005)) = 112\ psi$$

$$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123\ psi$$

$v_c < v_u \leq 2v_c$ USE v_c $\therefore v_u' = .112 = 112$ psi



METHOD #2

$s_l/d_l = \frac{12}{20.25} = .59$, $\frac{TD_b}{d_l} = \frac{7(.625)}{20.25} = .216$

FROM FIG. 6-19 OF TM5, $\alpha = 66°$

$$A_T = \frac{v_u'\,S_l\,b_l}{.85\,f_s\,(\sin\alpha + \cos\alpha)} = \frac{(112)(12)(12)}{.85(60000)(\sin 66 + \cos 66)}$$

$A_T = .24\ in^2$

USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 7 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: DKT DATE: 2 Sept 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

LONG BAY WALL C

SUMMARY -

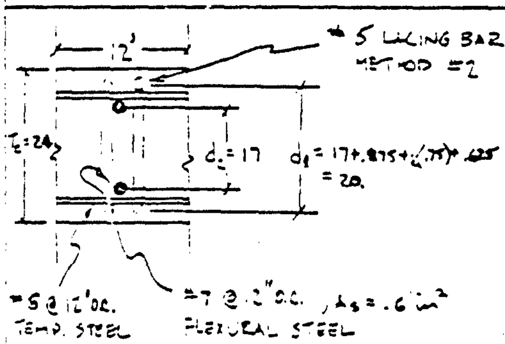
$T_c = 24''$
FLEX - #7 @ 12
TEMP - #6 @ 12
LACING - #5 @ 12

COMPUTER OUTPUT -

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS     F1 =   .1232E+05      F2 =   .3120E+04
                    T2 =   .6300E-02      T4 =   .1000E+02

BEAM PARAMETERS     L =  155.00      THICK =    24.00
     D =   3.50     D' =   3.50
     ROTATION =  1.00      TNATL =    .107E-01

FC' =     4000.      FDY =   72000.

IE =  .1152E+04      IC =  .6087E+02      IA =  .5354E+03
KEL =  .2231E+06      KELPL =  .4461E+05
 L1 =  .2756E+04          L2 =  .3575E+04

REQUIRED STEEL AREA =    .0293 SQ IN/IN =    .3513 SQ IN/FT
```

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING / LONG BAY / WALL C
BY: D KETCHUM DATE: AUGUST 19 86 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 13$ FT $= 156$ in

$$M = \frac{A_s f_s d_c}{b}$$

$$M = \frac{.6\ (72000)\ 17}{12} = 6.1 \times 10^4\ \frac{in\text{-}lb}{in}$$

$$r_u = \frac{16 M}{L^2} = \frac{16\ (6.1 \times 10^4)}{(156)^2} = 40\ psi$$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(17) = .51\ in^2$
TEMP. BAR, $A_s > .0015\ b d_c = .0015(12)(17) = .31\ in^2$
$A_T = $ #6 BAR $= .44\ in^2 > A_s/4$

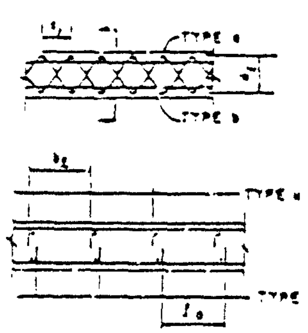
$$v_u = \frac{r_u\ (\frac{L}{2} - d_c)}{d_c} = \frac{40(\frac{156}{2} - 17)}{17} = 143.5\ psi$$

$$p = A_s / d_c b = \frac{.6}{(12)(17)} = .0029$$

$$v_c = \phi\ (1.9 \sqrt{f'_c} + 2500\ p) = .85(1.9\sqrt{4000} + 2500(.0029)) = 108\ psi$$

$$v_{c\ max} = 2.28\ \phi \sqrt{f'_c} = 2.28\ (.85) \sqrt{4000} = 123\ psi$$

$v_c < v_u$ & 2.75 USE v_c $\therefore v_c' = 108 = 108$ psi



METHOD #2

$S_l / d_l = \frac{12}{20.} = .60$, $\frac{7 D_0}{d_l} = \frac{7(.625)}{20} = .22$

FROM FIG. 6-19 OF TM5 , $\alpha = 67°$

$$A_T = \frac{v_c'\ S_l\ b_l}{.85\ f_s\ (\sin\alpha + \cos\alpha)} = \frac{(108)(12)(12)}{.85(60000)(\sin 67 + \cos 67)}$$

$A_T = .23\ in^2$

USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: J.K. DATE: 9/24 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

LONG BAY DIVIDING WALL

SUMMARY –
MAX DEFLECTION = 8.09°
T_c = 12"
FLEX = #5 @ 12
TEMP = #4 @ 12
COMP. OUTPUT – LACING = #5 mem 2

STRUCTURAL ELEMENT : DIVIDING WALL

LOADS ON 1" SECTION :
PEAK SHOCK FORCE = .5800E+05 LB
PEAK QUASI-STATIC FORCE = ********* LB
SHOCK FORCE DURATION = .3500E-03 SEC
QUASI-STATIC FORCE DURATION = .1000E+01 SEC

MATERIAL STRENGTHS :
FC' = 4000. PSI
FDY = 90000. PSI

CROSS-SECTION :
TOTAL CONCRETE THICKNESS = 12.0 INCHES
COVER (TOP AND BOTTOM) = 2.00 INCHES
EFFECTIVE STEEL MOMENT ARM = 7.00 INCHES
STEEL SIZE AND SPACING = # 5 AT 12 INCHES
STEEL AREA (EACH FACE) = .31 SQ IN/FT

SUPPORT CONDITIONS : FIXED - FIXED

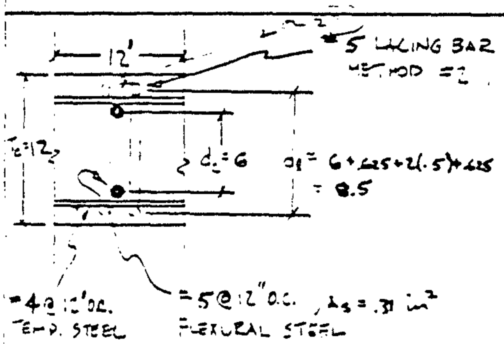
RESPONSE
MAXIMUM DEFLECTION = 5.82 INCHES
MAXIMUM ROTATION = 8.09 DEGREES

REACTIONS
RU = .284E+02 LB/IN
END REACTION = .164E+02 KIP/FT

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING / LONG BAY / DIVIDING WALL
BY: D. Ketchum DATE: 24 SEPT 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 __

LACING DESIGN –



FIXED-FIXED SUPPORTS
$L = 12\ FT = 144\ in$

$M = \frac{A_s f_y d_c}{b}$

$M = \frac{.31 (90\,000)\,6}{12} = 1.1 \times 10^4\ \frac{in\text{-}lb}{in}$

$r_u = \frac{16 M}{L^2} = \frac{16\ (1.1 \times 10^4)}{(144)^2} = 8.7\ psi$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(6) = .18\ in^2$
TEMP. BAR, $A_s > .0015\ b d_c = .0015(12)(6) = .11\ in^2$
A_T = #4 BAR = .20 $in^2 > A_s/2$ ✓

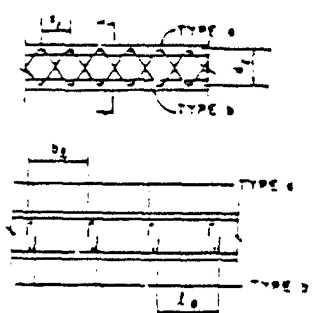
$v_u = \frac{r_u (\frac{L}{2} - d_c)}{d_c} = \frac{8.7(\frac{144}{2} - 6)}{6} = 95.7\ psi$

$p = A_s / d_c b = \frac{.31}{(6)(12)} = .0043$

$v_c = \phi (1.9 \sqrt{f'_c} + 2500\, p) = .85(1.9\sqrt{4000} + 2500(.0043)) = 111\ psi$

$v_{c\,max} = 2.28\, \phi \sqrt{f'_c} = 2.28 (.85) \sqrt{4000} = 123\ psi$

$v_c > v_u$ use v_c $\therefore v'_c = 111 = 111\ psi$



METHOD #2

$s_l / d_l = \frac{12}{8.5} = 1.4$, $\frac{7 D_0}{d_l} = \frac{7(.625)}{8.5} = .51$

FROM FIG. 6-19 OF TM5, $\alpha = 40°$

$A_d = \frac{v'_c\, s_l\, b_l}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{(111)(12)(12)}{.85(75\,000)(\sin 40 + \cos 40)}$

$A_d = .18\ in^2$

USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 11 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: DK DATE: 9/24 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

DOUBLE STACKED WALL A

SUMMARY –

$T_c = 24"$
FLEX = #7 @ 12
TEMP = #6 @ 12
LACING = #5 Ltem. 2

COMPUTER OUTPUT –

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS    F1 =  .2211E+06     F2 =  .2352E+04
                   T2 =  .4000E-03     T4 =  .1000E+02

BEAM PARAMETERS    L =  240.00      THICK =   24.00
     D =  3.50      D' =  3.50
     ROTATION =  1.00       TMAIL =   .253E-01

FC' =     4000.      FDY =   72000.

IE =  .1152E+04      IC =  .6885E+02      IA =  .5104E+03
KEL =  .6165E+05     KELP =  .1233E+05
 L1 =  .2099E+04      L2 =  .2798E+04

REQUIRED STEEL AREA =     .0343 SQ IN/IN =     .4115 SQ IN/FT
```

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

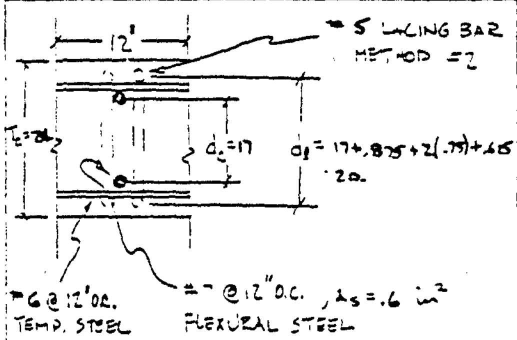
SHEET NO. 12 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT: LACING/DOUBLE STACKED/WALL A

BY: D KETCHUM DATE: 23 SEPT 19 83 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

LACING DESIGN -



FIXED-FIXED SUPPORTS

L = 20 FT = 240 in

$$M = \frac{A_s f_s d_c}{b}$$

$$M = \frac{.6\ (72000)\ 17}{12} = 6.1 \times 10^4\ \frac{\text{in-lb}}{\text{in}}$$

$$r_u = \frac{16 M}{L^2} = \frac{16\ (6.1 \times 10^4)}{(240)^2} = 17\ \text{psi}$$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(17) = .51$ in²

TEMP. BAR, $A_T > .0015\ b d_c = .0015(12)(17) = .31$ in²

A_T = #6 BAR = .44 in² $> A_s/4$

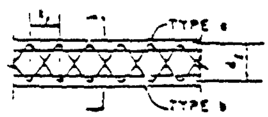
$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{17\left(\frac{240}{2} - 17\right)}{17} = 103\ \text{psi}$$

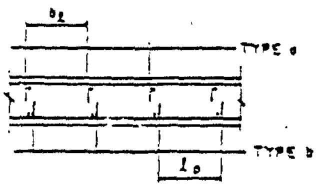
$$p = A_s / d_c b = \frac{.6}{(17)(12)} = .0029$$

$$v_c = \phi\ (1.9\sqrt{f'_c} + 2500\, p) = .85(1.9\sqrt{4000} + 2500(.0029)) = 108\ \text{psi}$$

$$v_{c\,max} = 2.28\ \phi\ \sqrt{f'_c} = 2.28\ (.85)\ \sqrt{4000} = 123\ \text{psi}$$

$v_c < v_{c\,max}$ USE v_c $\therefore v_c' = 108 = 108$ psi





METHOD #2

$$s_l/d_l = \frac{12}{20} = .6\ , \quad \frac{7 D_b}{d_l} = \frac{7(.625)}{20.} = .22$$

FROM FIG. 6-19 OF TM5, $\alpha = 67°$

$$A_v = \frac{v_u' s_l b_l}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{108(12)(12)}{.85(60{,}000)(\sin 67 + \cos 67)}$$

A_v = .23 in²

use #5 BAR

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: Dietrich DATE: 9/2 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

Double Stacked Wall B

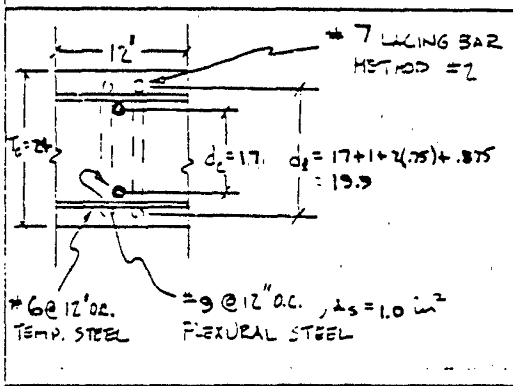
Summary –

$T_c = 24''$
Flex – #9 @ 12
Temp – #6 @ 12
Lacing – #7 Meth. 2

Computer Output –

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS   F1 =  .5549E+06     F2 =  .2638E+04
                  T2 =  .3300E-03     T4 =  .1000E+02

BEAM PARAMETERS   L =  .96.00     THICK =   24.00
    D =  3.50       D' =  3.50
    ROTATION =  1.00      TNATL =   .396E-02

FC' =    4000.     FDY =   72000.

IE =  .1152E+04     IC =  .1230E+03      IA =  .5375E+03
KEL =  .1006E+07     KELPL =  .2012E+06
 L1 =  .1070E+05          L2 =  .1427E+05

REQUIRED STEEL AREA =    .0699 SQ IN/IN =    .8393 SQ IN/FT
```

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 8$ FT $= 96$ in

$M = \frac{A_s f_s d_c}{b}$

$M = \frac{1.0\,(72000)\,17}{12} = 1.0 \times 10^5 \ \frac{\text{in-lb}}{\text{in}}$

$r_u = \frac{16 M}{L^2} = \frac{16\,(1.0 \times 10^5)}{(96)^2} = 177$ psi

FLEX. BAR, $A_s > .0025\, b d_c = .0025(12)(17) = .51$ in²
TEMP. BAR, $A_t > .0015\, b d_c = .0015(12)(17) = .31$ in²
$A_t = \#6$ BAR $= .44$ in² $> A_s/4$

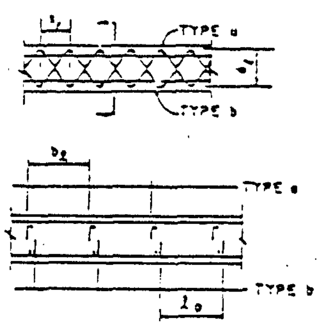
$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{177\left(\frac{96}{2} - 17\right)}{17} = 323$ psi

$p = A_s / d_c b = \frac{1.0}{(17)(12)} = .005$

$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.005)) = 113$ psi

$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123$ psi

$V_u > 2V_c$ use $V_u - V_c$ $\therefore v_u' = 323 - 113 = 210$ psi



METHOD #2

$s_\ell / d_\ell = \frac{12}{19.9} = .60$, $\frac{7D_b}{d_\ell} = \frac{7(.875)}{19.9} = .31$

FROM FIG. 6-19 of TM5 , $\alpha = 70°$

$A_v = \frac{v_u'\, s_\ell\, b_\ell}{.85\, f_s\,(\sin\alpha + \cos\alpha)} = \frac{(210)(12)(12)}{.85(60000)(\sin 70 + \cos 70)}$

$A_v = .46$ in²

use #7 BAR

PROJECT NO.: 02-7012 SPONSOR: CERL
SUBJECT: Reinforcing for Requirements
BY: D Kossover DATE: 9/24/1982 CHECKED BY: DATE CHECKED: 19

Double Stacked Wall C

Summary –

$T_c = 24''$
Flex = #9@12
Temp = #6@12
Lacing = #5@12

Computer Output –

FIXED – FIXED SUPPORT CONDITIONS

LOAD PARAMETERS F1 = .1469E+05 F2 = .6048E+04
T2 = .6800E-02 T4 = .1000E+02

BEAM PARAMETERS L = 216.00 THICK = 24.00
D = 3.50 D' = 3.50
ROTATION = 1.00 TNATL = .230E-01

FC' = 4000. FDY = 72000.

IE = .1152E+04 IC = .1261E+03 IA = .5391E+03
KEL = .8855E+05 KELPL = .1771E+05
L1 = .4904E+04 L2 = .5539E+04

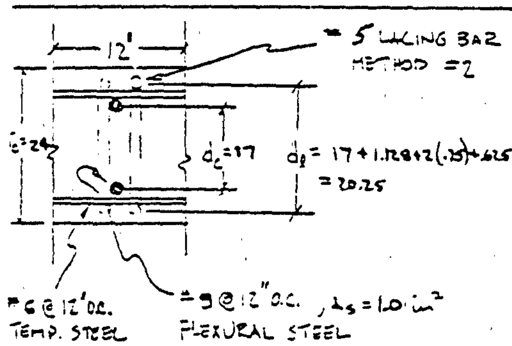
REQUIRED STEEL AREA = .0721 SQ IN/IN = .8654 SQ IN/FT

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 16 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING / DOUBLE STACKED / WALL C
BY: DS DATE: 24 Sept 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 18\ FT = 216\ in$

$M = \dfrac{A_s f_s d_c}{b}$

$M = \dfrac{1.0\,(72000)\,17}{12} = 1.0 \times 10^5\ \dfrac{in\text{-}lb}{in}$

$r_u = \dfrac{16 M}{L^2} = \dfrac{16\,(1.0 \times 10^5)}{(216)^2} = 35\ psi$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(17) = .51\ in^2$
TEMP. BAR, $A_t > .0015\ b d_c = .0015(12)(17) = .31\ in^2$
$A_t = \#6$ BAR $= .44\ in^2 > A_s/2$

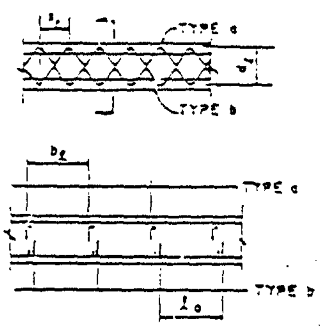
$v_u = \dfrac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \dfrac{35\left(\frac{216}{2} - 17\right)}{17} = 187\ psi$

$p = A_s / d_c b = \dfrac{1.0}{(17)(12)} = .005$

$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.005)) = 112\ psi$

$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123\ psi$

$V_c < V_u \leq 2V_c$ use V_c $\therefore v'_u = 112 = 112\ psi$



METHOD #2

$S_\ell / d_\ell = \dfrac{12}{20.25} = .59$, $\dfrac{7 D_b}{d_\ell} = \dfrac{7(.625)}{20.25} = .216$

FROM FIG. 6-19 OF TM5, $\alpha = 66°$

$A_T = \dfrac{v'_u\, S_\ell\, b_\ell}{.85\, f_s\,(\sin\alpha + \cos\alpha)} = \dfrac{(112)(12)(12)}{.85(60\,000)(\sin 66 + \cos 66)}$

$A_T = .24\ in^2$

USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 17 OF 32

PROJECT NO.: 02 - 7092 SPONSOR: CERL
SUBJECT: REINFORCING BAR REQUIREMENTS
BY: D Ketchum DATE: 28 Sept 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

Double Stacked Dividing Wall

Summary -
Max. Rotation = 5.44°
T_c = 12"
Flex - #5 @ 12
Temp - #4 @ 12
Lacing - #7 @ 12

Computer output -

STRUCTURAL ELEMENT : DIV WALL

LOADS ON 1" SECTION :
PEAK SHOCK FORCE = .5549E+05 LB
PEAK QUASI-STATIC FORCE = ********* LB
SHOCK FORCE DURATION = .3300E-03 SEC
QUASI-STATIC FORCE DURATION = .1000E+01 SEC

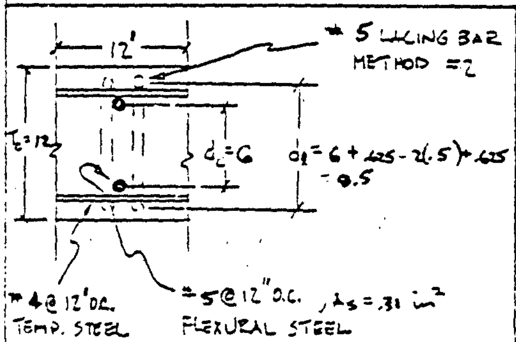
MATERIAL STRENGTHS :
FC' = 4000. PSI
FDY = 90000. PSI

CROSS-SECTION :
TOTAL CONCRETE THICKNESS = 12.0 INCHES
COVER (TOP AND BOTTOM) = 2.00 INCHES
EFFECTIVE STEEL MOMENT ARM = 7.00 INCHES
STEEL SIZE AND SPACING = # 5 AT 12 INCHES
STEEL AREA (EACH FACE) = .31 SQ IN/FT
EFFECTIVE MOMENT OF INERTIA I = .9113E+03 IN**4/FT
PLASTIC MOMENT CAPACITY = .1966E+03 KIP-IN/FT
ELEMENT LENGTH = 144.00 INCHES
NATURAL PERIOD = .1323E-01 SECONDS

SUPPORT CONDITIONS : FIXED - FIXED

RESPONSE
MAXIMUM DEFLECTION = 9.13 INCHES
MAXIMUM ROTATION = 5.44 DEGREES

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 8$ FT $= 96$ in

$$M = \frac{A_s f_s d_c}{b}$$

$$M = \frac{.31(90000)\,6}{12} = 1.4 \times 10^4 \ \frac{\text{in-lb}}{\text{in}}$$

$$r_u = \frac{16M}{L^2} = \frac{16\,(1.4\times10^4)}{(96)^2} = 24 \text{ psi}$$

FLEX. BAR, $A_s > .0025\, b d_c = .0025(12)(6) = .18$ in^2,
TEMP. BAR, $A_T > .0015\, b d_c = .0015(12)(6) = .13$ in^2
$A_T = $ #4 BAR $= .20$ in$^2 > A_s/4$

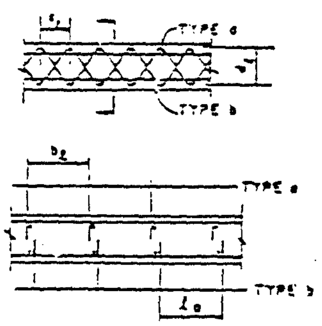
$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{24\left(\frac{96}{2} - 6\right)}{6} = 168 \text{ psi}$$

$$p = A_s / d_c b = \frac{.31}{(6)(12)} = .0043$$

$$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.0043)) = 111 \text{ psi}$$

$$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123 \text{ psi}$$

$v_c < v_u < 2v_c$ use v_c $\therefore v_u' = 111 = 111$ psi



METHOD #2

$S_l/d_l = \frac{12}{8.5} = 1.4$, $\frac{7D_o}{d_l} = \frac{7(.625)}{8.5} = .51$

FROM FIG. 6-19 OF TM5, $\alpha = 40°$

$$A_T = \frac{v_u' S_l b_l}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{(111)(12)(12)}{.85(75000)(\sin 40 + \cos 40)}$$

$A_T = .18$ in^2

use #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 19 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: [illegible]
BY: [illegible] DATE: 24 Sept 19 92 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

PITS WALL A

SUMMARY -
T_c = 24"
FLEX = #10 @ 12
TEMP = #6 @ 12
LACING = #5 @ 12

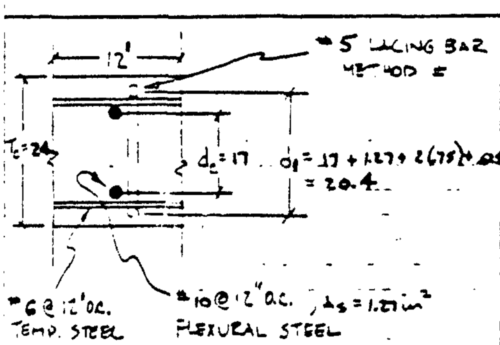
COMPUTER OUTPUT -

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS   F1 =  .3600E+06     F2 =  .4080E+04
                  T2 =  .5800E-03     T4 =  .1000E+02

BEAM PARAMETERS   L =  240.00     THICK =   24.00
    D =  3.50      D' =  3.50
    ROTATION =  1.00      TNATL =   .244E-01

FC' =    4000.     FDY =   72000.

IE =  .1152E+04     IC =  .1544E+03     IA =  .5532E+03
KEL =  .6599E+05     KELP_ =  .1320E+05
 L1 =  .5641E+04        L2 =  .7522E+04

REQUIRED STEEL AREA =     .0922 SQ IN/IN =   1.1061 SQ IN/FT
```

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING/PITS/WALL A
BY: D Ketchum DATE: 23 Sept 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

LACING DESIGN



FIXED-FIXED SUPPORTS

$L = 20$ FT $= 240$ in

$M = \frac{A_s f_y d_c}{b}$

$M = \frac{1.27(71{,}000)\,17}{12} = 1.3 \times 10^5 \; \frac{in\text{-}lb}{in}$

$r_u = \frac{16 M}{L^2} = \frac{16(1.3 \times 10^5)}{(240)^2} = 36$ psi

FLEX. BAR, $A_s > .0025\, b d_c = .0025(12)(17) = .51 \, in^2$ ✓
TEMP BAR, $A_T > .0015\, b d_c = .0015(12)(17) = .31 \, in^2$
$A_T = \#6$ BAR $= .44 \, in^2 > A_{s/2}$ ✓

$v_u = \frac{r_u (\frac{L}{2} - d_c)}{d_c} = \frac{36(\frac{240}{2} - 17)}{17} = 218$ psi

$p = A_s / d_c b = \frac{1.27}{(17)(12)} = .0062$

$v_c = \phi(1.9\sqrt{f'_c} + 2500 p) = .85(1.9\sqrt{4000} + 2500(.0062)) = 115$ psi

$v_{c\,max} = 2.28 \phi \sqrt{f'_c} = 2.28(.85)\sqrt{4000} = 123$ psi

$V_c < V_u < 2V_c$ USE V_c $\therefore v_c' = 115 = 115$ psi

$S_l / d_l = \frac{12}{20.4} = .59$, $\frac{7 D_0}{d_l} = \frac{7(1)}{20.4} = .34$

FROM FIG 5-19 OF TM5, $\alpha = 73°$

$A_T = \frac{v_c' S_l b_l}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{(115)(12)(12)}{.85(60{,}000)(\sin 73 + \cos 73)}$

$A_T = .26 \, in^2$

USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 21 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: D ___ DATE ___ 19 82 CHECKED BY ___ DATE CHECKED: ___ 19 ___

Pits Wall B

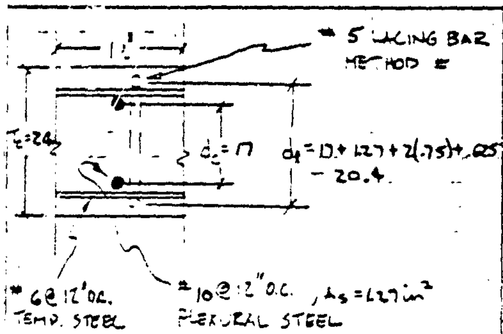
Summary -

$T_c = 24"$
Flex - #10 @ 12
Temp - #6 @ 12
Lacing - #5 meth. 2

Computer Output -

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS   F1 =  .7680E+06     F2 =  .4080E+04
                  T2 =  .3600E-03     T4 =  .1000E+02

BEAM PARAMETERS   L =  240.00      THICK =   24.00
    D =  3.50       D' =  3.50
    ROTATION =  1.00      THATL =   .243E-01

FC' =    4000.     FDY =   72000.

IE =  .1152E+04     IC =  .1701E+03     IA =  .5511E+03
KEL =  .6673E+05     KELP =  .1336E+05
L1 =  .6351E+04        L2 =  .3468E+04

REQUIRED STEEL AREA =    .1038 SQ IN/IN =   1.2454 SQ IN/FT
```

LACING DESIGN



FIXED-FIXED SUPPORTS

$L = 20\ FT = 240\ in$

$$M = \frac{A_s f_y d_c}{b}$$

$$M = \frac{1.27(72{,}000)\ 17}{12} = 1.3 \times 10^5\ \frac{in\text{-}lb}{in}$$

$$r_u = \frac{16M}{L^2} = \frac{16\ (1.3\times10^5)}{(240)^2} = 36\ psi$$

FLEX. BAR, $A_s > .0025\ bd_c = .0025(12)(17) = .51\ in^2$ ✓

TEMP. BAR, $A_s > .0015\ bd_c = .0015(12)(17) = .38\ in^2$

A_T = #6 BAR = $.44\ in^2 > A_{s/3}$ ✓

$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{36\left(\frac{240}{2} - 17\right)}{17} = 218\ psi$$

$$p = A_s / d_c b = \frac{1.27}{(17)(12)} = .0062$$

$$v_c = \phi\ (1.9\sqrt{f'_c} + 2500\ p) = .85(1.9\sqrt{4000} + 2500(.0062)) = 115\ psi$$

$$v_{c\ max} = 2.28\ \phi\ \sqrt{f'_c} = 2.28\ (.85)\sqrt{4000} = 123\ psi$$

$V_c < V_u < 2V_c$ USE V_c $\therefore v_u' = 115 = 115\ psi$

$$S_l/d_l = \frac{12}{20.4} = .59,\quad \frac{T_c}{d_l} = \frac{7(.625)}{20.4} = .23$$

FROM FIG. 6-19 OF TM5, $\alpha = 70°$

$$A_T = \frac{v_u' S_l b_l}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{(115)(12)(12)}{.85(60{,}000)(\sin 70 + \cos 70)}$$

$A_T = .25\ in^2$

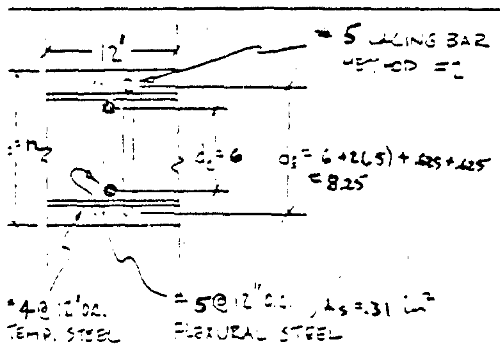
USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 23 OF 32

PROJECT NO.: 02-7097 SPONSOR: CERL
SUBJECT: LACING/PITS/DIVIDING WALL
BY: D. KETCHUM DATE: 24 SEPT 19 82 CHECKED BY: DATE CHECKED: 19

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 5\ FT = 60\ in$

$M = \frac{A_s f_y d_c}{b}$

$M = \frac{.31\ (36000)\ 6}{12} = 1.4 \times 10^4\ \frac{in\text{-}lb}{in}$

$r_u = \frac{16 M}{L^2} = \frac{16\ (1.4 \times 10^4)}{(60)^2} = 62\ psi$

FLEX. BAR $A_s > .0025\ b d_c = .0025(12)(6) = .18\ in^2$
TEMP BAR $A_s > .0015\ b d_c = .0015(12)(6) = .13\ in^2$
$A_s = \#4\ BAR = .20\ in^2 > A_s/2$

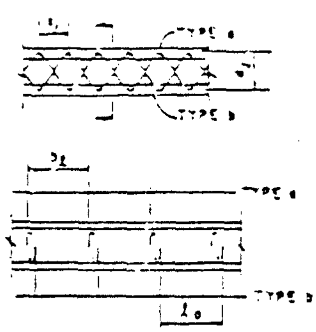
$v_u = \frac{r_u\ (\frac{L}{2} - d_c)}{d_c} = \frac{62(\frac{60}{2} - 6)}{6} = 248\ psi$

$p = A_s / d_c b = \frac{.31}{(6)(12)} = .0043$

$v_c = \phi\ (1.9 \sqrt{f'_c} + 2500\ p) = .85 (1.9 \sqrt{4000} + 2500\ (.0043)) = 111\ psi$

$v_{c\ max} = 2.28\ \phi \sqrt{f'_c} = 2.28\ (.85) \sqrt{4000} = 123\ psi$

$V_u > 2V_c$ USE $V_u - V_c$ $\therefore v_u' = 248 - 111 = 137\ psi$



METHOD #2

$S_L / d_L = \frac{12}{8.25} = 1.45$, $\frac{TD_s}{d_L} = \frac{7(.625)}{8.25} = .53$

FROM FIG 6-19 OR THIS, $\alpha = 40°$

$A_V = \frac{v_u'\ S_L\ b_L}{.85\ f_s\ (\sin\alpha + \cos\alpha)} = \frac{(137)(12)(12)}{.85(75000)(\sin 40 + \cos 40)}$

$A_V = .22\ in^2$

USE #5 BAR

MAINTENANCE BAY WALL

SUMMARY—

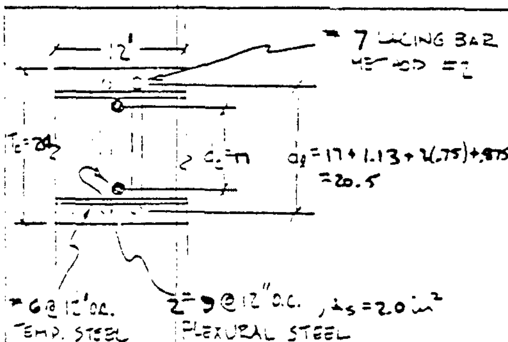
$T_c = 24''$
FLEX = 2 #9 @ 12
TEMP = #6 @ 12
LACING = #7 METHOD 2

COMPUTER OUTPUT—

```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS   F1 =  .6643E+06     F2 =  .8880E+04
                  T2 =  .3000E-03     T4 =  .1000E+02

BEAM PARAMETERS   L =  240.00      THICK =   24.00
    D =  3.50     D' =  3.50
    ROTATION =  1.00      TNATL =    .239E-01

FC' =    4000.      FDY =   72000.

IE =  .1152E+04     IC =  .2178E+03     IA =  .5849E+03
KEL =  .6913E+05     KELP =  .1384E+05
 L1 =  .8659E+04       L2 =  .1155E+05

REQUIRED STEEL AREA =    .1415 SQ IN/IN =    1.6979 SQ IN/FT
```

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING / MAINTENANCE BAY / WALL
BY: D KETTLER DATE: 23 SEPT 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

LACING DESIGN -



FIXED-FIXED SUPPORTS
$L = 20\ FT = 240\ in$

$M = \dfrac{A_s f_s d_c}{b}$

$M = \dfrac{2.0\ (72000)\ 17}{12} = 2.0 \times 10^5\ \dfrac{in\text{-}lb}{in}$

$r_u = \dfrac{16 M}{L^2} = \dfrac{16\ (2.0 \times 10^5)}{(240)^2} = 57\ psi$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(17) = .51\ in^2$
TEMP. BAR, $A_s > .0015\ b d_c = .0015(12)(17) = .38\ in^2$
$A_s =$ # 6 BAR $= .44\ in^2 > A_s/2$

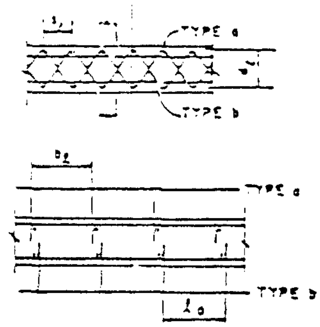
$v_u = \dfrac{r_u\ (\frac{L}{2} - d_c)}{d_c} = \dfrac{(57)(\frac{240}{2} - 17)}{17} = 343\ psi$

$p = A_s / d_c b = \dfrac{2.0}{(17)(12)} = .010$

$v_c = \phi\ (1.9 \sqrt{f'_c} + 2500\ p) = .85(1.9\sqrt{4000} + 2500(.010)) = 123\ psi$

$v_{c\ max} = 2.28\ \phi \sqrt{f'_c} = 2.28\ (.85) \sqrt{4000} = 123\ psi$

$v_u > 2v_c$ USE $v_u - v_c$ $\therefore v_u' = 343 - 123 = 220\ psi$



METHOD # 2

$S_\ell / d_\ell = \dfrac{12}{20.5} = .55$, $\dfrac{7 D_b}{d_\ell} = \dfrac{7(1)}{20.5} = .32$

FROM FIG. 6-19 OF TM5, $\alpha = 75°$

$A_v = \dfrac{v_u'\ S_\ell\ b_\ell}{.85\ f_s\ (\sin\alpha + \cos\alpha)} = \dfrac{(220)(12)(12)}{.85(60000)(\sin 75 + \cos 75)}$

$A_v = .51\ in^2$

USE # 7 BAR

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: Dietchuis DATE: 24 Sep 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

MAZE WALL A

SUMMARY -

T_c = 24"
FLEX - #7 @ 12
TEMP - #6 @ 12
LACING - #5 METHOD 2

COMPUTER OUTPUT -

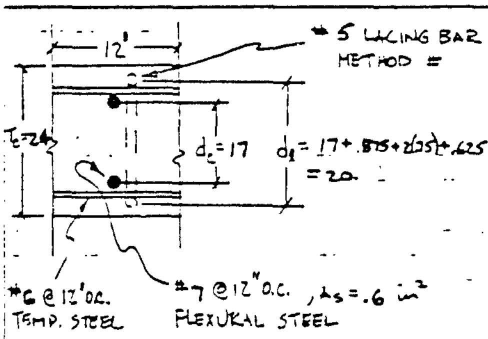
```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS    F1 =  .1757E+06      F2 =  .1824E+04
                   T2 =  .5100E-03      T4 =  .1000E+02

BEAM PARAMETERS    L =  240.00      THICK =   24.00
     D =  3.50      D' =  3.50
     ROTATION =  1.00      TNATL =   .253E-01

FC' =     4000.      FDY =    72000.

IE =  .1152E+04      IC =  .5212E+02      IA =  .5071E+03
KEL =  .5132E+05      KELPL =  .1226E+05
 L1 =  .1840E+04         L2 =  .2453E+04

REQUIRED STEEL AREA =    .0301 SQ IN/IN =    .3507 SQ IN/FT
```

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 27 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING/MAZE/WALL A
BY: D KETCHUM DATE: 23 SEPT 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 20$ FT $= 240$ in

$M = \frac{A_s f_y d_c}{b}$

$M = \frac{.6\,(72{,}000)\,17}{12} = 4.3\times10^4 \frac{\text{in-lb}}{\text{in}}$

$r_u = \frac{16M}{L^2} = \frac{16\,(4.3\times10^4)}{(240)^2} = 12$ psi

FLEX. BAR, $A_s > .0025\, b d_c = .0025(12)(17) =$ in² ✓
TEMP. BAR, $A_T > .0018\, b d_c = .0018(12)(17) =$ in²
$A_T =$ #6 BAR $= .44$ in² $> A_s/4$ ✓

$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{12\left(\frac{240}{2} - 17\right)}{17} = 73$ psi

$p = A_s / d_c b = \frac{.6}{(17)(12)} = .0029$

$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.0029)) = 108.4$ psi

$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123$ psi

$V_c > V_u$ USE V_c $\therefore v_u' = 108 = 108$ psi

$S_\ell / d_\ell = \frac{12}{20.} = .6$, $\frac{7D_b}{d_\ell} = \frac{7(.625)}{20} = .22$

FROM FIG. 6-19 OF TM5, $\alpha = 67°$

$A_T = \frac{v_u'\, S_\ell\, b_\ell}{.85 f_s (\sin\alpha + \cos\alpha)} = \frac{(108)(12)(12)}{.85(60{,}000)(\sin 67 + \cos 67)}$

$A_T = .23$ in²

use #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 28 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: [illegible] DATE: 24 Sept 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

Maze Wall B

Summary -

$T_c = 24''$
Flex = #10 @ 12
Temp = #6 @ 12
Lacing = #5 Meth. 2

Computer Output -

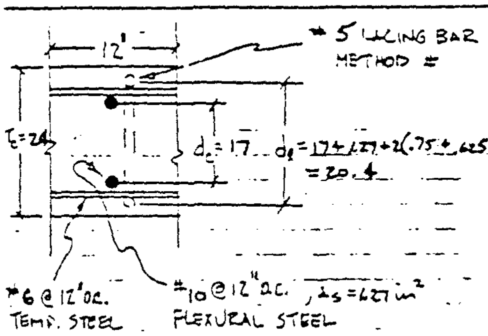
```
FIXED - FIXED SUPPORT CONDITIONS

LOAD PARAMETERS    F1 =  .5208E+06     F2 =  .4550E+04
                   T2 =  .4000E-03     T4 =  .1000E+02

BEAM PARAMETERS    L =  240.00      THICK =   24.00
     D =   3.50      D' =   3.50
     ROTATION =  1.00      TNATL =   .245E-01

FC' =     4000.      FDY =   72000.

IE =  .1152E+04     IC =  .1471E+03     IA =  .6495E+03
KEL =  .6561E+05     KELPL =  .1312E+05
 L1 =  .5316E+04        L2 =  .7088E+04

REQUIRED STEEL AREA =    .0869 SQ IN/IN =   1.0423 SQ IN/FT
```

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT: LACING / MAZE / WALL B

BY: D KETCHUM DATE: 23 SEPT 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

LACING DESIGN



FIXED - FIXED SUPPORTS

$L = 20$ FT $= 240$ in

$$M = \frac{A_s f_s d_c}{b}$$

$$M = \frac{1.27(12{,}000)\,17}{12} = 1.3 \times 10^5 \ \frac{in\text{-}lb}{in}$$

$$r_u = \frac{16M}{L^2} = \frac{16\,(1.3 \times 10^5)}{(240)^2} = 36\ psi$$

FLEX. BAR, $A_s > .0025\, bd_c = .0025(12)(17) = .51\ in^2$ ✓

TEMP. BAR, $A_T > .0018\, bd_c = .0018(12)(17) = .38\ in^2$

$A_T =$ #6 BAR $= .44\ in^2 > A_{s/2}$ ✓

$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{36\left(\frac{240}{2} - 17\right)}{17} = 218 \ psi$$

$$p = A_s / d_c b = \frac{1.27}{(17)(12)} = .0062$$

$$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.0062)) = 115\ psi$$

$$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123\ psi$$

$V_u > V_c$ USE V_c $\therefore v_u' = 115 = 115$ psi

$$S_l/d_l = \frac{12}{20.4} = .59\ , \quad \frac{7D_0}{d_l} = \frac{7(.625)}{20.4} = .21$$

FROM FIG. 6-19 OF TM5, $\alpha = 67°$

$$A_T = \frac{v_u'\, S_l\, b_l}{.85 f_s\,(\sin\alpha + \cos\alpha)} = \frac{(115)(12)(12)}{.85(60{,}000)(\sin 67 + \cos 67)}$$

$A_T = .25\ in^2$

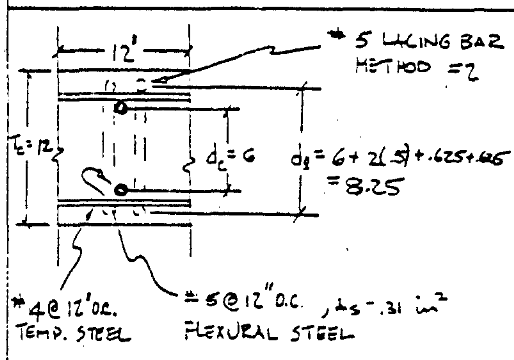
USE #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 30 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING/MAZE/DIVIDING WALL
BY: DKETCHUM DATE: 24 SEPT 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

LACING DESIGN -



FIXED-FIXED SUPPORTS

$L = 5\ FT = 60\ in$

$M = \dfrac{A_s f_s d_c}{b}$

$M = \dfrac{.31\ (96000)\ 6}{12} = 1.4 \times 10^4\ \dfrac{in\text{-}lb}{in}$

$r_u = \dfrac{16 M}{L^2} = \dfrac{16\ (1.4 \times 10^4)}{(60)^2} = 62\ psi$

FLEX. BAR, $A_s > .0025\ b d_c = .0025(12)(6) = .18\ in^2$

TEMP. BAR, $A_s > .0015\ b d_c = .0015(12)(6) = .13\ in^2$

$A_T = {}^{\#}4$ BAR $= .60\ in^2 > A_s/4$ ✓

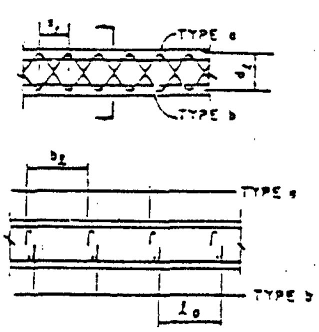
$v_u = \dfrac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \dfrac{62\left(\frac{60}{2} - 6\right)}{6} = 248\ psi$

$p = A_s / d_c b = \dfrac{.31}{(6)(12)} = .0043$

$v_c = \phi\ (1.9\sqrt{f'_c} + 2500\ p) = .85(1.9\sqrt{4000} + 2500(.0043)) = 111\ psi$

$v_{c\ max} = 2.28\ \phi \sqrt{f'_c} = 2.28\ (.85)\sqrt{4000} = 123\ psi$

$V_u > 2V_c$ use $V_u - V_c$ $\therefore v_u' = 248 - 111 = 137\ psi$



METHOD #2

$S_l / d_l = \dfrac{12}{8.25} = 1.45, \quad \dfrac{\pi D_0}{d_l} = \dfrac{\pi(.625)}{8.25} = .53$

FROM FIG. 6-19 OF TM5, $\alpha = 40°$

$A_r = \dfrac{v_u'\ S_l\ b_l}{.85\ f_s\ (\sin\alpha + \cos\alpha)} = \dfrac{(137)(12)(12)}{.85(75000)(\sin 40 + \cos 40)}$

$A_r = .22\ in^2$

use #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 31 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Reinforcing Bar Requirements
BY: [illegible] DATE: 20 Sept 1983 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

Double Stacked Ceiling/Floor

Summary -

$T_c = 36"$.

Flexural Bar = (2) #9 @ 12

Temp. Bar = #7 @ 12

Lacing Bar = #5 method 2

Computer Output -

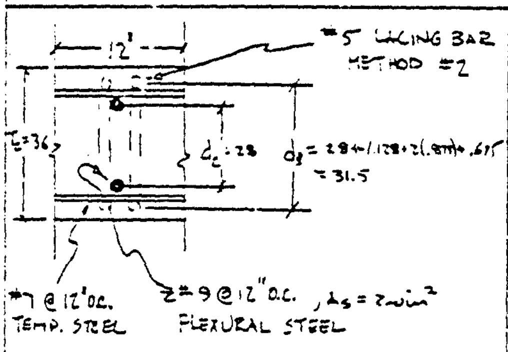
```
MAINT ROOF

FIXED EDGES

PRESSURE - TIME VALUES
          TIME              PRESS
   0.                   .23800E+03
    .27000E-02          .37000E+02
    .20000E+01          .37000E+02

SLAB PARAMETERS    A =   540.00       B =   660.00
    THICK =    36.00     TOP COVER =      4.00      BOTTOM COVER =      4.00
    MAX DEFL =      4.70      TNATL  =    .628E-01

FCP =     4000.      FDY =      72000.


IE =  .2838E+04       IC =   .6484E+03       IA =   .2268E+04
EL =  .1994E+08      KELPL =   .5997E+07
L1 =  .7493E+07         L2 =   .1547E+08
MOMENT =  .2838E+06

REQUIRED STEEL AREA =     .1408 SQ IN/IN =    1.6894 SQ IN/FT

STEEL AREA IN EACH FACE FOR DOUBLY REINFORCED SECTION

BAR SIZE & SPACING      AREA (SQ IN/FT) = (SQ IN/IN)
        #10 @  9"                  1.69          .1408
        # 9 @  7"                  1.71          .1425
```

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 32 OF 32

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LACING / DOUBLE STACKED / CEILING – 5 ARR
BY: D Ketchum DATE: 30 Sept 89 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

LACING DESIGN –



FIXED-FIXED SUPPORTS
L = 45 FT = 540 in

$$M = \frac{A_s f_{ds} d_c}{b}$$

$$M = \frac{2.0\ (72000)\ 28}{12} = 3.4 \times 10^5\ \frac{\text{in-lb}}{\text{in}}$$

$$r_u = \frac{16\ M}{L^2} = \frac{16\ (3.4 \times 10^5)}{(540)^2} = 18.6\ \text{psi}$$

FLEX. BAR, A_s > .0025 bd_c = .0025(12)(28) = .84 in²,
TEMP. BAR, A_s > .0018 bd_c = .0018(12)(28) = .60 in²
A_s = #7 BAR = .60 in² > A_s

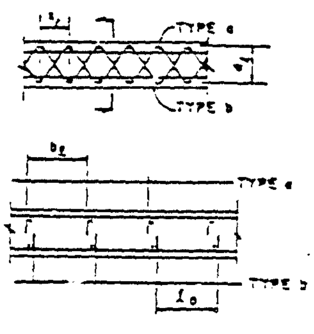
$$v_u = \frac{r_u\left(\frac{L}{2} - d_c\right)}{d_c} = \frac{18.6\left(\frac{540}{2} - 28\right)}{28} = 153.\ \text{psi}$$

$$p = A_s / d_c b = \frac{2.0}{(28)(12)} = .006$$

$$v_c = \phi\ (1.9\sqrt{f'_c} + 2500\ p) = .85(1.9\sqrt{4000} + 2500(.006)) = 103.4\ \text{psi}$$

$$v_{c\,max} = 2.28\ \phi\sqrt{f'_c} = 2.28\ (.85)\sqrt{4000} = 123\ \text{psi}$$

$v_u > v_c$ use v_c $\therefore v_u' = 103 = 103$ psi



METHOD #2

$$S_\ell / d_\ell = \frac{12}{31.5} = .38\ ,\quad \frac{7 D_0}{d_\ell} = \frac{7(.625)}{31.5} = .14$$

FROM FIG. 6-19 OF TM5, α = 76°

$$A_v = \frac{v_u' S_\ell b_\ell}{.85 f_s\ (\sin\alpha + \cos\alpha)} = \frac{(103)(12)(12)}{.85(60,000)(\sin 76 + \cos 76)}$$

A_v = .24 in²

use #5 BAR

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 8

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST DOOR
BY: M. WHITNEY DATE: 3 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

BLAST DOOR DESIGN SUMMARY

LOADING

	LONG BAY	PIT BAY
P_{SHOCK}	= 100 psi	180
t_{SHOCK}	- 0.0046 SEC	3.2×10^{-3}
P_{QUASI}	= 21 psi	26

FRAGMENT : 1.6 in STEEL MIN

PLATE

2 in THICK

A36 STEEL

RESPONSE - ELASTIC

REBOUND PINS

14 - 1.0 in DIAMETER PINS

ANCHOR BOLTS

20 - 1.5 in DIAMETER BOLTS

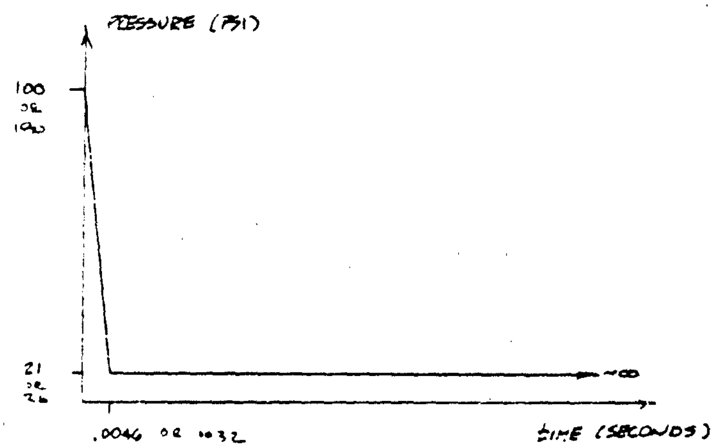
$\frac{1}{2}$ in PLATE LINING JAM

JAM FORMED INTO CONCRETE

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST DOOR DESIGN
BY: M. WHITNEY DATE: 17 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ______

BLAST LOADING

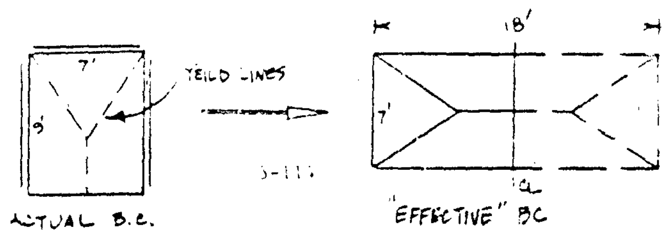


FRAGMENT LOADING

MINIMUM STEEL PL THICKNESS = 1.6 in

BOUNDARY CONDITION

THE DOOR WILL BE SUPPORTED ON THREE EDGES BY THE JAM. THE FLOOR EDGE WILL BE FREE. THE DOOR WILL BE ANALYZED AS A 4 SIDED SIMPLY-SUPPORTED PLATE OF TWICE THE AREA AS SHOWN. THE LOAD WILL BE APPLIED TO THE ENTIRE "EFFECTIVE" AREA.



THE STIFFNESS AND RESISTANCES FOR AN EQUIVALENT 1 DOF SYSTEM ARE OBTAINED FROM THE SUPPRESSIVE SHIELDS MANUAL.(1) THESE VALUES ARE USED AS INPUT INTO A 1 D.O.F. COMPUTER PROGRAM FOR THE DETERMINATION OF DEFLECTION.

FOR THIS DOOR:

$$\frac{a}{b} = \frac{WIDTH}{LENGTH} = \frac{7'}{18'} = 0.39$$

THE CLOSEST VALUE IN THE SUPPRESSIVE SHIELDS MANUAL IS $\frac{a}{b} = 0.5$, USE THIS VALUE. THE CORRESPONDING TERMS ARE:

STRAIN	a/b	K_{LM}	L_1	K
ELASTIC	.5	0.75	$\frac{1}{a}(12M_a + 9M_b)$	$201 EI_a / a^2$
PLASTIC	.5	0.59	$\frac{1}{a}(12M_a + 9M_b)$	0

WHERE $M_a = \sigma Z_a = \frac{\sigma a t^2}{4}$, t = PLATE THICKNESS
$\sigma = \sigma_y \times DLF$
DLF = 1.2, DYNAMIC LOAD FACTOR

$$M_b = \sigma Z_a = \frac{\sigma b t^2}{4}$$

E = YOUNG'S MODULUS

$$I_a = \frac{1}{12}\frac{a t^3}{a} \quad 3\text{-}113$$

ALSO, MASS = ρV, LOADS = $P a b$, $X_{EL} = L_1/K$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST DOOR
BY: M. WHITNEY DATE: 7 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

CONSIDER A SOLID STEEL PLATE ($a = 84$ in, $b = 216$ in)

WITH A36 STEEL, $\sigma_y = 36$ KSI

$$\sigma = 36 \times 1.2 = 43.2 \text{ KSI}$$

THE MINIMUM PLATE THICKNESS IS FIXED BY FRAG. PENETRATION AS 1.5 in.
DETERMINE STIFFNESS AND RESISTANCE VALUES FOR BOTH A 1.6 in AND 2 in PLATE:

	t THICKNESS (IN) 1.6	2.0
$M_a = \frac{\sigma a t^2}{4}$	$(43200)(84)(1.6)^2/4 = 2.3\times10^6$ lb-in	$(43200)(84)(2)^2/4 = 3.6\times10^6$ lb-in
$M_b = \frac{\sigma b t^2}{4}$	$(43{,}200)(216)(1.6)^2/4 = 6.0\times10^6$ lb-in	$(43{,}200)(216)(2)^2/4 = 9.2\times10^6$ lb-in
$L_1 = \frac{1}{a}\left[12 M_a + 9 M_b\right]$	$\frac{1}{84}\left[12(2.3\times10^6) + 9(6.0\times10^6)\right] = 9.7\times10^5$ lb	$\frac{1}{84}\left[12(3.6\times10^6) + 9(9.2\times10^6)\right] = 1.5\times10^6$ lb
$I_a = \frac{1}{12}\frac{a t^3}{a}$	$\frac{1}{12}(1.6)^3 = .34\ \frac{in^4}{in}$	$\frac{1}{12}(2)^3 = .67\ \frac{in^4}{in}$
$K = K_{EL} = \frac{201\, E I_a}{a^2}$ (ELASTIC)	$\frac{201(30\times10^6)(.34)}{(84)^2} = 2.9\times10^5\ \frac{lb}{in}$	$\frac{201(30\times10^6)(.67)}{(84)^2} = 5.7\times10^5\ \frac{lb}{in}$
MASS $= \rho V$	$(1.6)(84)(216)(7.4\times10^{-4}) = 21\ \frac{lb\text{-}s^2}{in}$	$2(84)(216)(7.4\times10^{-4}) = 27$ lb-s²/in
$X_{EL} = L_1/K_{EL}$	$9.7\times10^5/2.9\times10^5 = 3.3$ in	$1.5\times10^6/5.7\times10^5 = 2.6$ in
$F_1 = P_1 a b$ (120 ft PIT) $F_2 = P_2 a b$ (120 ft PIT)	$100(84)(216) = 1.8\times10^6$ lb or $180(84)(216) = 3.3E6$ $21(84)(216) = 3.8\times10^5$ lb or $2\ldots(84)(216) = 4.7E5$	1.8×10^6 lb or $3.3E6$ 3.8×10^5 lb or $4.7E5$

THE RESULTS ARE AS FOLLOWS, COMPUTER OUTPUT ATTACHED.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST DOOR
BY: M. WHITNEY DATE: 17 AUG 1982 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

THE DESIGNS FOR THE TWO BAYS ARE SO SIMILAR, ONLY THE 120x90 DESIGN ARE DISCUSSED FURTHER. THE PIT AND OTHER BAY DOORS WILL HAVE THE SAME DESIGN.

THICKNESS	MAX. DEFL. (X)	ELASTIC DEFL. (X_{EL})	STRAIN RATIO X/X_{EL}	MAX ROTATION $\arctan\left(\frac{2X}{a}\right)$
1.6	3.5	3.3	1.1	4.8°
2.0	1.9	2.6	0.73	2.6°

TYPICALLY BLAST RESISTANT DOORS ARE ALLOWED SOME PLASTIC DEFORMATION SUCH AS SUGGESTED IN "DESIGN OF STEEL STRUCTURES TO RESIST THE EFFECTS OF HE EXPLOSIONS" BY HEALEY ET. AL (REF. 2). FOR PLATE ELEMENTS REF. 2 SUGGESTS

$$\text{REUSABLE DESIGN}: \theta_{MAX} = 2° \text{ OR } \frac{X}{X_{EL}} = 5$$

$$\text{NON-REUSABLE DESIGN}: \theta_{MAX} = 4° \text{ OR } \frac{X}{X_{EL}} = 10$$

BOTH THE 1.6 in AND 2.0 in PLATES MEET THE X/X_{EL} REUSEABLE CRITERIA. FOR THE VALUE OF $a = 84$ in, THE ROTATIONS OF 4.8° AND 2.6° ARE NOT EXCESSIVE. EITHER PLATE THICKNESS WOULD PROVIDE THE PROTECTION DESIRED, HOWEVER FOR LITTLE EXTRA COST, THE 2 in PLATE WILL PROVIDE ELASTIC RESPONSE ($X/X_{EL} < 1$). IN ADDITION,

ADDITIONAL SAFETY FOR FRAGMENT PROTECTION IS PROVIDED.

REBOUND

BECAUSE TOTAL CONTAINMENT IS REQUIRED, THE DOOR MUST WITHSTAND REBOUND. THIS WILL BE PROVIDED BY SHEAR PINS WHICH SLIDE INTO AND OUT OF THE JAM AS THE DOOR IS OPERATED. THE SHEAR PINS MUST WITHSTAND THE ENTIRE REBOUND SHEAR. FROM TM5-1300 (3) SHEAR IS DETERMINED BY CONSIDERING L_1, THE ULTIMATE RESISTANCE, OF THE PLATE APPLIED AS A STATIC LOAD. AS SHOWN EARLIER IN THE COMPUTER OUTPUT, THE DOOR DEVELOPES LESS THAN L_1 IN REBOUND. THIS VALUE IS:

$$L_R = 3.2 \times 10^5 \text{ lbs}$$, REBOUND RESISTANCE, MAX.

THIS IS APPLIED AS A STATIC LOAD

$$V_R = L_R = 3.2 \times 10^5 \text{ lbs}$$

USE STEEL SHEAR PINS WITH $\sigma_y = 60,000$ psi

$$\tau_y = .55\,\sigma_y = .55\,(60,000) = 33,000 \text{ psi}$$

D.L.F. FOR SHEAR = 1.0 , $\tau = \tau_y$

AREA OF SHEAR STEEL REQUIRED FOR REBOUND

$$A_{S,R} = \frac{V_{TOT}}{\tau} = \frac{3.2 \times 10^5 \text{ lb}}{33{,}000 \text{ psi}} = 9.7 \text{ in}^2$$

THIS WILL BE PROVIDED BY 14 - 1" DIAMETER BOLTS

$$14\left[\frac{\pi D^2}{4}\right] = \frac{14(3.14)(1.0)^2}{4} = 11. \text{ in}^2 > 9.7 \text{ in}^2 \text{ req'd.}$$

THE SHEAR PINS CAN BE ARRANGED AS 5 PER SIDE 4 AT TOP, AND 0 AT BOTTOM. BY THIS PLACEMENT, THE 3 SIDED SIMPLY-SUPPORTED RESPONSE IS ALSO DEVELOPED IN REBOUND.

DOOR JAM

THE DOOR JAM IS REQUIRED TO WITHSTAND THE SUPPORT SHEARS AS THE DOOR DEFLECTS OUTWARD. THE MAXIMUM RESISTANCE DEVELOPED BY THE DOOR IS PROVIDED IN THE COMPUTER OUTPUT DISCUSSED EARLIER AS,

$$L_{max} = 1.1 \times 10^6 \text{ lb}$$

AGAIN, THIS IS EQUATED TO THE SHEAR LOAD

$$V_{MAX} = L_{MAX} = 1.1 \times 10^6 \text{ lb}$$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 8 OF 8

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST DOOR DESIGN
BY: W. WHITNEY DATE: 17 AUG 19 8_ CHECKED BY: ______ DATE CHECKED: ______ 19 ___

AREA OF STEEL REQUIRED FOR JAM:

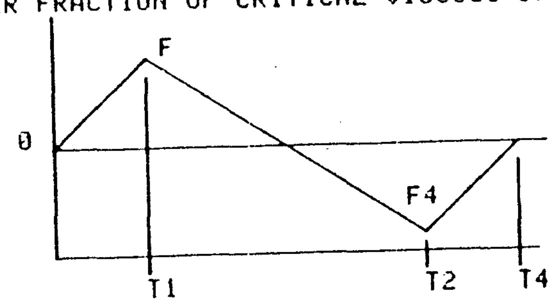
$$A_{s,J} = \frac{V_{TOT}}{\tau} = \frac{1.1 \times 10^6}{33000} = 33 \text{ in}^2$$

THIS AREA IS PROVIDED BY 20 - 1.5 in dia BOLTS

$$19 \left[\pi \frac{(1.5)^2}{4} \right] = 34 \text{ in}^2 > 33 \text{ Reqd}$$

THE SHEAR BOLTS CAN BE PLACED AS 12 ON EACH SIDE AND 10 ACROSS THE TOP. A JAM WILL BE FORMED INTO THE CONCRETE ON THE THREE SIDES OF THE DOOR TO PROVIDE A LIP FOR THE DOOR. IN ADDITION A $\frac{1}{2}$ in PLATE TO WHICH THE ANCOR BOLTS WILL BE ATTACHED WILL LINE THE JAM LIP.

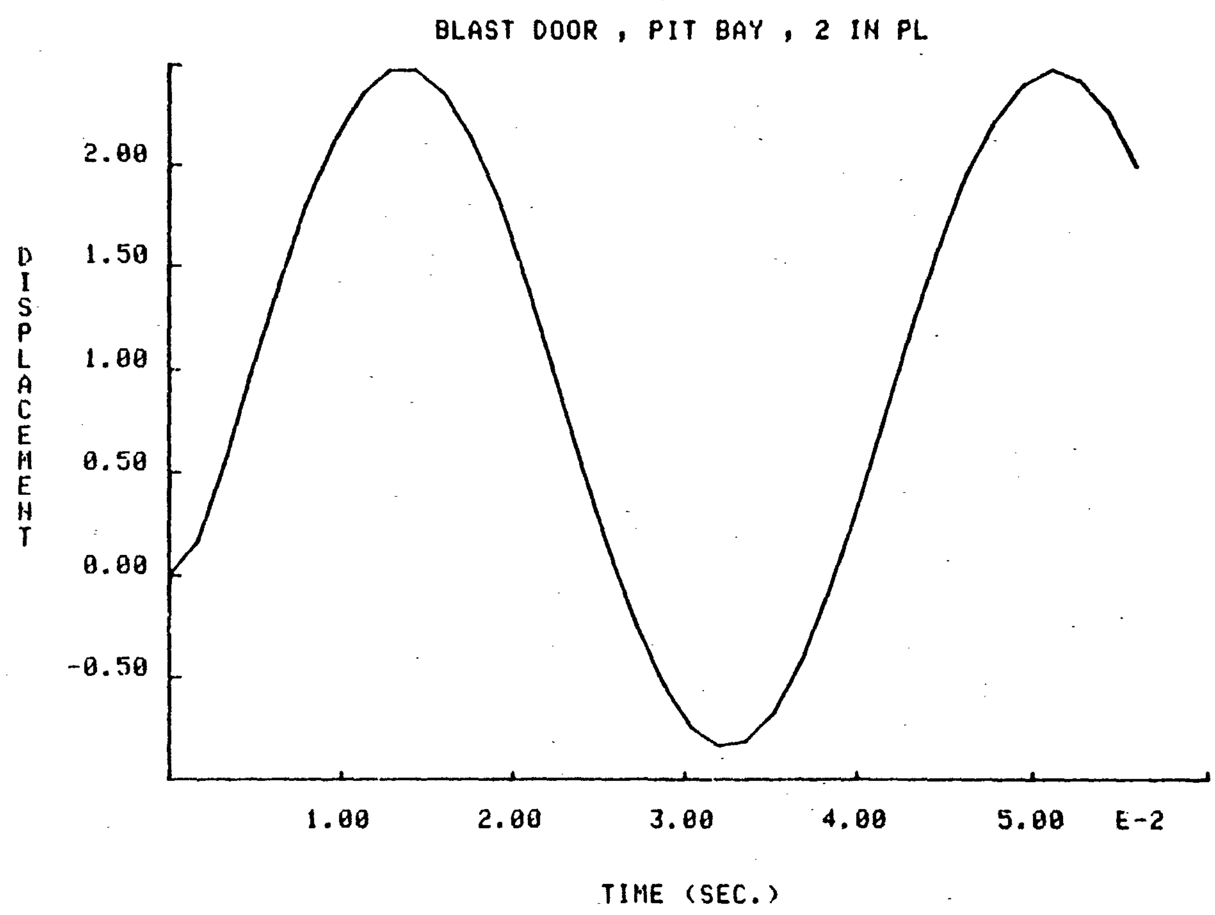
```
BLAST DOOR , PIT BAY , 2 IN PL

ENTER THE MASS. M= 27
ENTER THE MASS-LOADED FACTORS.      K9(1)= .75   K9(2)= .59   K9(3)= .59

ENTER THE ELASTIC SPRING CONSTANT. K= 5.7[redacted]

ENTER THE ELAS-PLAS. SPRING CONSTANT. K5= 0

ENTER THE YIELD LOAD FOR THE SPRING. L1= 1.5E6    L2= 1.5E6

ENTER FRACTION OF CRITICAL VISCOUS DAMPING. B=0
```




```
F= 3.3E6      T2= .0032
F4= 4.7E5     T4= 10
T1= 0

ENTER INITIAL DISPLACEMENT (D0) AND VELOCITY (V0).
D0=0          V0=0

THE PERIOD OF ELAS VIB., T7, IS      0.0374502701016  SEC

ENTER THE INTEGRATION TIME STEP, ABOUT T7/10. T3= .0016

ENTER THE NUMBER OF RESPONSE CYCLES OVER WHICH THE NUMERICAL
INTEGRATION IS TO BE PERFORMED. N1= 1.5
WANT COPY? (1 FOR YES, 2 FOR NO)1
```

TIME	DISP	FORCE	RESISTANCE
0	0	3300000	0
0.0016	0.160113848011	1885000	91264.8933663
0.0032	0.541190936704	470000	308478.833921
0.0048	0.985179623411	469924.775928	561552.385344
0.0064	1.41750518157	469849.551857	807977.953497
0.008	1.80757399997	469774.327785	1030317.17998
0.0096	2.12780245913	469699.103713	1212847.40171
0.0112	2.35556682561	469623.879641	1342673.0906
0.0128	2.47480091349	469548.65557	1410636.52069
0.0144	2.47712868952	469473.431498	1411963.35302
0.016	2.36245197919	469398.207426	1346597.62814
0.0176	2.13895204082	469322.983355	1219202.66327
0.0192	1.82250527658	469247.759283	1038828.00765
0.0208	1.43555480576	469172.535211	818266.239282
0.0224	1.00551810216	469097.31114	573145.318231
0.024	0.562843674107	469022.087068	320820.894241
0.0256	0.138854526398	468946.862996	79147.080047
0.0272	-0.236468858359	468871.638924	-134787.249265
0.0288	-0.536609101039	468796.414853	-305867.187592
0.0304	-0.740386077793	468721.190781	-422020.064342
0.032	-0.833452185205	468645.966709	-475067.745567
0.0336	-0.809303158084	468570.742638	-461302.800108
0.0352	-0.669733227739	468495.518566	-381747.939811
0.0368	-0.424702773865	468420.294494	-242080.581103
0.0384	-0.0916282164981	468345.070423	-52228.0834039
0.04	0.305855228935	468269.846351	174337.480493
0.0416	0.739570042467	468194.622279	421554.924206
0.0432	1.17879322086	468119.398207	671912.13589
0.0448	1.59243192408	468044.174136	907686.196723
0.0464	1.95122387966	467968.950064	1112197.61141
0.048	2.22980682591	467893.725992	1270989.89077
0.0496	2.40851064266	467818.501921	1372851.06632
0.0512	2.47474553656	467743.277849	1410604.95584

```
0.0528          2.42388831339     467668.053777     1381616.33863
0.0544          2.25960434962     467592.829706     1287974.47928
0.056           1.99358284643     467517.605634     1136342.22247
WANT COPY? (1 FOR YES, 2 FOR NO)1
```


BLAST DOOR , PIT BAY , 2 IN PL
DISPLACEMENT
2.00
1.50
1.00
0.50
0.00
-0.50
1.00
2.00
3.00
4.00
5.00
E-2
TIME (SEC.)

BLAST DOOR , PIT BAY , 1.6 IN PL

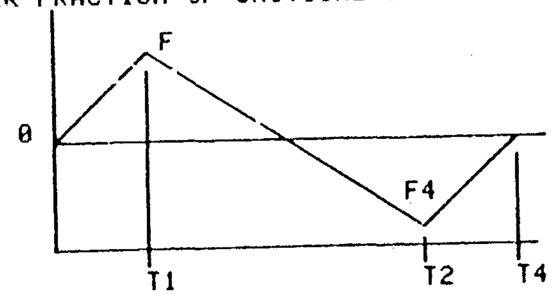
ENTER THE MASS. M= 21
ENTER THE MASS-LOADED FACTORS.   K9(1)= .75   K9(2)= .59   K9(3)= .59

ENTER THE ELASTIC SPRING CONSTANT. K= 2.9E5

ENTER THE ELAS-PLAS. SPRING CONSTANT. K5= 0

ENTER THE YIELD LOAD FOR THE SPRING. L1= 9.7E5   L2= 9.7E5

ENTER FRACTION OF CRITICAL VISCOUS DAMPING. B=0



F= 3.3E6   T2= .0032

F4= 4.7E5   T4= 10

T1= 0

ENTER INITIAL DISPLACEMENT (D0) AND VELOCITY (V0).
D0=0   V0=0

THE PERIOD OF ELAS VIB., T7, IS   0.0463042813716 SEC

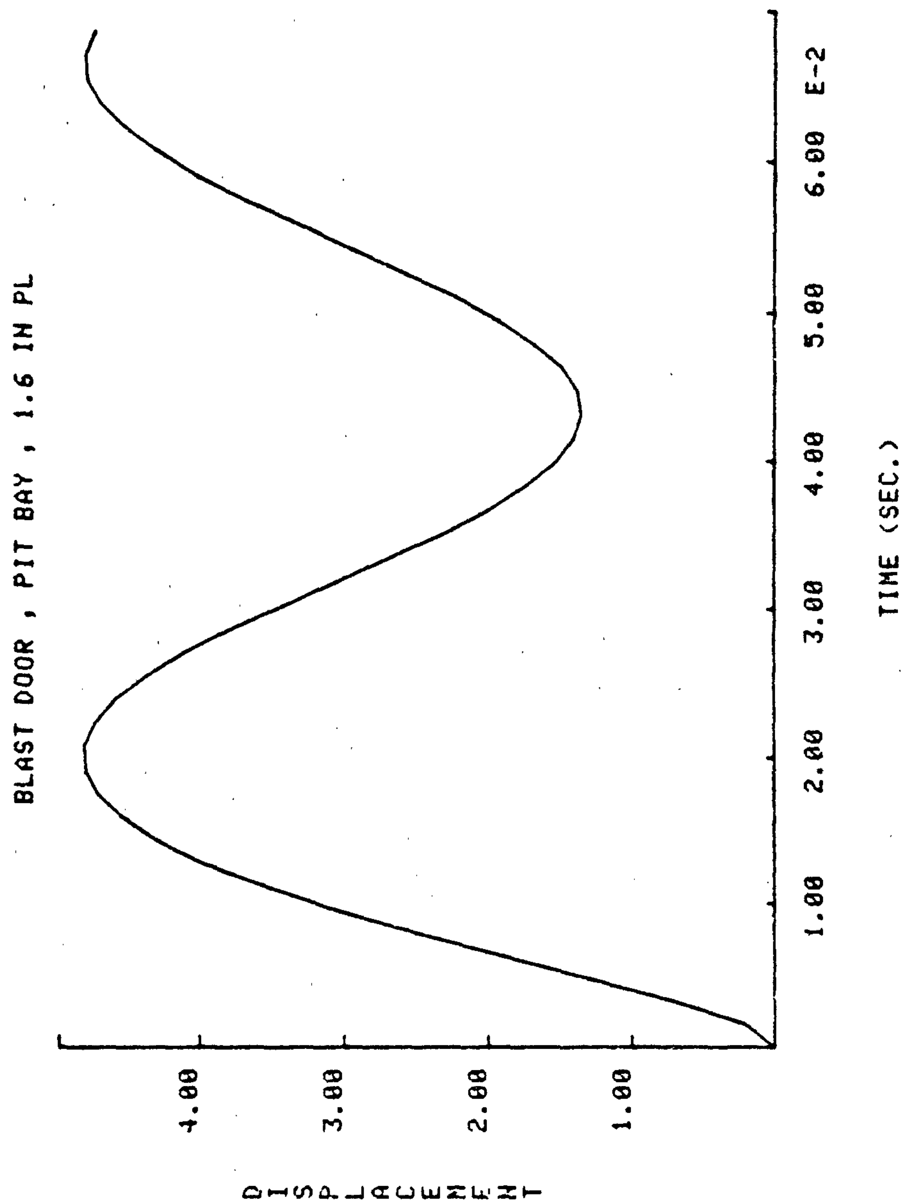
ENTER THE INTEGRATION TIME STEP, ABOUT T7/10. T3= .00[illegible]6

ENTER THE NUMBER OF RESPONSE CYCLES OVER WHICH THE NUMERICAL
INTEGRATION IS TO BE PERFORMED. N1= 1.5
WANT COPY? (1 FOR YES, 2 FOR NO)1

TIME	DISP	FORCE	RESISTANCE
0	0	3300000	0
0.0016	0.207531672065	1985000	60184.1851308
0.0032	0.706760322951	470000	204960.493656
0.0048	1.30456232406	469924.775928	378323.073978
0.0064	1.91691168353	469849.551857	555904.388225
0.008	2.51526840502	469774.327785	729427.837456
0.0096	3.07175221033	469699.103713	890888.140996
0.0112	3.5630505729	469623.879641	970000
0.0128	3.97623591462	469548.65557	970000
0.0144	4.30807805368	469473.431498	970000
0.016	4.5585647632	469398.207426	970000
0.0176	4.72768381628	469322.983355	970000
0.0192	4.81542298602	469247.759283	970000
0.0208	4.82177004552	469172.535211	970000
0.0224	4.74759721635	469097.31114	948489.879542
0.024	4.59644282228	469022.087068	904655.105261
0.0256	4.37535709036	468946.862996	840540.243004
0.0272	4.0946457644	468871.638924	759133.958476
0.0288	3.76738914848	468796.414853	664229.53986
0.0304	3.40883204215	468721.190781	560247.979023
0.032	3.03567302053	468645.966709	452031.862755
0.0336	2.66528619354	468570.742638	344619.682927
0.0352	2.31491171401	468495.518566	243011.083863
0.0368	2.00085275059	468420.294494	151933.984471
0.0384	1.73771632933	468345.070423	75624.422306
0.04	1.5377333942	468269.846351	17629.3711188
0.0416	1.41018973686	468194.622279	-19358.2895102
0.0432	1.36099427272	468119.398207	-33624.9741099
0.0448	1.39240473538	468044.174136	-24515.9399402
0.0464	1.50292352304	467968.950064	7534.50848068
0.048	1.68736850137	467893.725992	61023.552197
0.0496	1.93711541604	467818.501921	133450.157453
0.0512	2.24050057551	467743.277849	221431.853697

0.0528	2.58336500205	467668.053777	320862.537394
0.0544	2.94971466403	467592.829706	427103.939602
0.056	3.32246600821	467517.605634	535201.82918
0.0576	3.68424202418	467442.381562	640116.873814
0.0592	4.01818177314	467367.15749	736959.401011
0.0608	4.30872564068	467291.933419	821217.122596
0.0624	4.5423397593	467216.709347	888965.216998
0.064	4.70814586753	467141.485275	937048.988385
0.0656	4.79842729311	467066.261204	963230.601802
0.0672	4.80898752561	466991.037132	966293.069228
0.0688	4.73934471663	466915.81306	946096.654622

WANT COPY? (1 FOR YES, 2 FOR NO)1


BLAST DOOR , PIT BAY , 1.6 IN PL
DISPLACEMENT
4.00
3.00
2.00
1.00
1.00
2.00
3.00
4.00
5.00
6.00
E-2
TIME (SEC.)

BLAST DOOR , 120X40 BAY , 1.6 IN PL

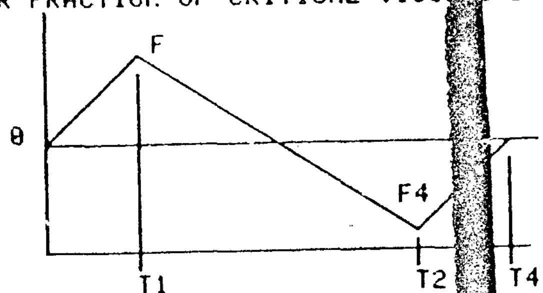
ENTER THE MASS. M= 21.
ENTER THE MASS-LOADED FACTORS.   K9(1)= .75   K9(2)= .59   K9(3)= .59

ENTER THE ELASTIC SPRING CONSTANT. K= 2.9E5

ENTER THE ELAS-PLAS. SPRING CONSTANT. K5= 0

ENTER THE YIELD LOAD FOR THE SPRING. L1= 9.7E5   L2= 9.7E5

ENTER FRACTION OF CRITICAL VISCOUS DAMPING. B=0



F= 1.8E6   T2= .0046

F4= 3.8E5   T4= 10

T1= 0

ENTER INITIAL DISPLACEMENT (D0) AND VELOCITY (V0).
D0=0   V0=0

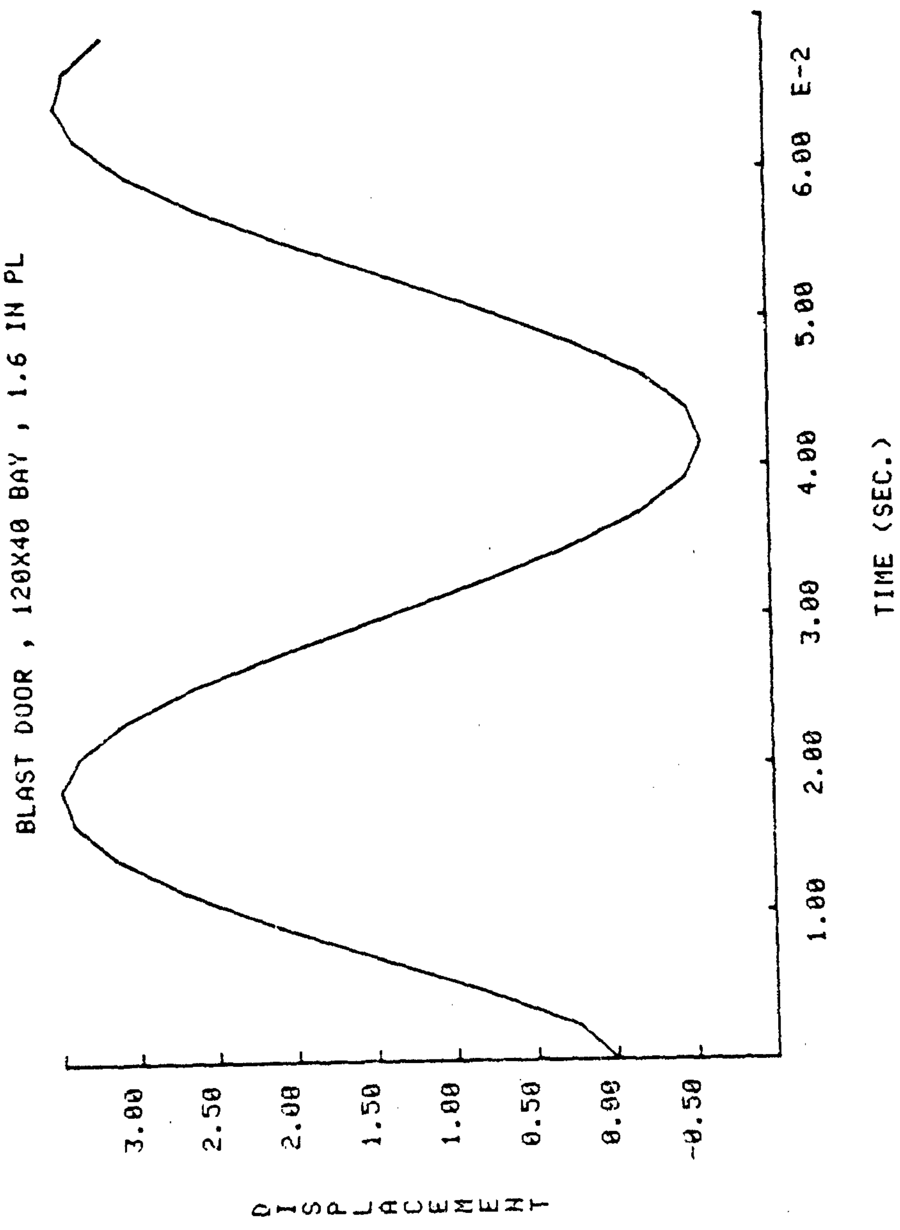
THE PERIOD OF ELAS VIB., T7, IS   0.0463042813716 SEC

ENTER THE INTEGRATION TIME STEP, ABOUT T7/10. T3= .0023

ENTER THE NUMBER OF RESPONSE CYCLES OVER WHICH THE NUMERICAL
INTEGRATION IS TO BE PERFORMED. = 1.5
WANT COPY? (1 FOR YES, 2 FOR NO)

TIME	DISP	FORCE	RESISTANCE
0	0	1800000	0
0.0023	0.235307356916	1090000	68239.1335057
0.0046	0.802257344649	380000	232654.629948
0.0069	1.47352585617	379912.559778	427322.49829
0.0092	2.12846197399	379825.119555	617253.972456
0.0115	2.70481696304	379737.679333	784396.919282
0.0138	3.14788357964	379650.23911	912886.238094
0.0161	3.41757443228	379562.798887	970000
0.0184	3.49374910437	379475.358665	970000
0.0207	3.3745571596	379387.918442	935434.336016
0.023	3.07329300067	379300.47822	848067.729924
0.0253	2.61877343111	379213.037997	716257.054753
0.0276	2.05434514549	379125.597775	552572.851924
0.0299	1.43374820402	379038.157552	372599.738899
0.0322	0.81599671745	378950.71733	193451.807792
0.0345	0.259764403	378863.277107	32144.4366016
0.0368	-0.182190853311	378775.836885	-96022.5877286
0.0391	-0.468033633046	378688.396662	-179916.993852
0.0414	-0.570813707602	378600.95644	-208723.215473
0.0437	-0.481009501598	378513.516217	-182679.995732
0.046	-0.207412271821	378426.075995	-103336.799097
0.0483	0.223731055195	378338.635772	21694.7657381
0.0506	0.771232864577	378251.19555	180470.290459
0.0529	1.38289668543	378163.755327	357852.798506
0.0552	2.00049054652	378076.315105	536955.018223
0.0575	2.56528799562	377988.874882	700746.27846
0.0598	3.02364953873	377901.43466	833671.125963
0.0621	3.33211403986	377813.994437	923125.831291
0.0644	3.46151681979	377726.554215	960652.637471
0.0667	3.39974425988	377639.113992	942738.595096
0.069	3.15286475408	377551.67377	871143.538415

WANT COPY? (1 FOR YES, 2 FOR NO)1


BLAST DOOR , 120X40 BAY , 1.6 IN PL
DISPLACEMENT
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
1.00
2.00
3.00
4.00
5.00
6.00
E-2
TIME (SEC.)

BLAST DOOR , 120X40 BAY , 2 in

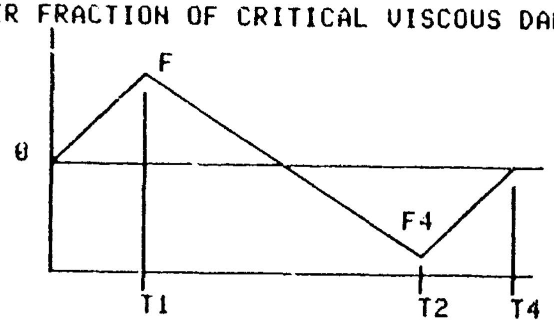
ENTER THE MASS. M= 27
ENTER THE MASS-LOADED FACTORS.   K9(1)= .73   K9(2)= .59   K9(3)= .59

ENTER THE ELASTIC SPRING CONSTANT. K= 5.7E5

ENTER THE ELAS-PLAS. SPRING CONSTANT. K5= 0

ENTER THE YIELD LOAD FOR THE SPRING. L1= 1.5E6   L2= 1.5E6

ENTER FRACTION OF CRITICAL VISCOUS DAMPING. B=0



F= 1.8E6   T2= .0046

F4= 3.8E5   T4= 10

T1= 0

ENTER INITIAL DISPLACEMENT (D0) AND VELOCITY (V0).
D0=0   V0=0

THE PERIOD OF ELAS VIB., T7, IS   0.0374502701016 SEC

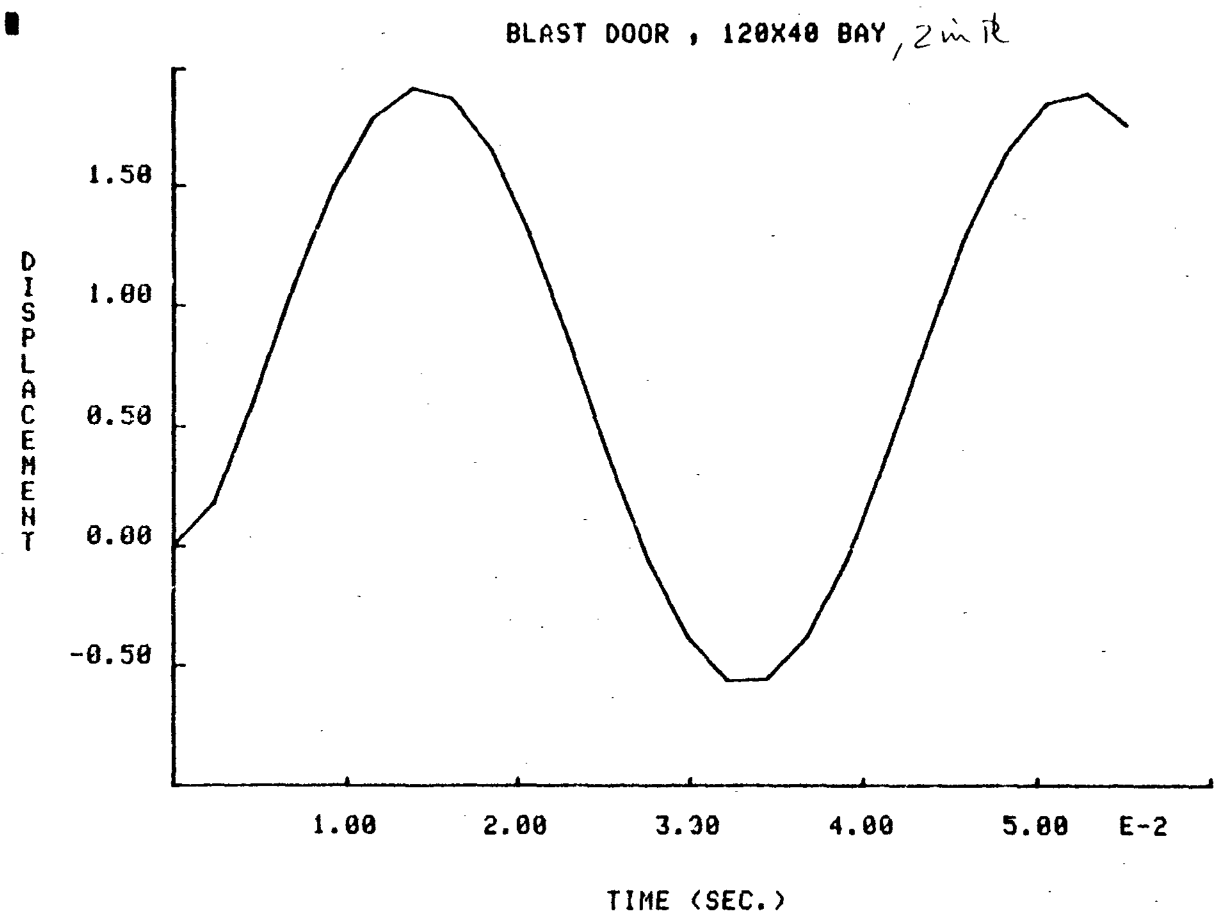
ENTER THE INTEGRATION TIME STEP, ABOUT T7/10. T3= .0023

ENTER THE NUMBER OF RESPONSE CYCLES OVER WHICH THE NUMERICAL
INTEGRATION IS TO BE PERFORMED. N1= 1.5
WANT COPY? (1 FOR YES, 2 FOR NO)1

BLAST DOOR, 120X40 BAY, 2 in PL

TIME	DISP (INCHES)	FORCE	RESISTANCE
0	0	1800000	0
0.0023	0.179989746502	1090000	102594.155506
0.0046	0.604370691174	380003	344491.293969
0.0069	1.07941739464	379912.559778	615267.914942
0.0092	1.49395286781	379825.119555	851553.134652
0.0115	1.78869476315	379737.679333	1019556.015
0.0138	1.9216987187	379650.23911	1095368.26966 MAX.
0.0161	1.87432347515	379562.798887	1068364.38084
0.0184	1.65383871298	379475.358665	942688.066398
0.0207	1.29231105332	379387.918442	736617.300391
0.023	0.841938241405	379300.47822	479904.797601
0.0253	0.367510250985	379213.037997	209480.843061
0.0276	-0.0629139467127	379125.597775	-35860.9496262
0.0299	-0.387772419804	379038.157552	-221030.279288
0.0322	-0.560807826016	378950.71733	-319660.460829
0.0345	-0.557656476935	378863.277107	-317864.191853
0.0368	-0.379280452502	378775.836885	-216189.857926
0.0391	-0.0517594852663	378688.396662	-29502.9066018
0.0414	0.377517460934	378600.95644	215184.952732
0.0437	0.84670496184	378513.516217	482621.828249
0.046	1.28840739812	378426.075995	734392.21693
0.0483	1.63935552161	378338.635772	934433.043179
0.0506	1.84946870885	378251.19555	1054197.16405
0.0529	1.88899135931	378163.755327	1076725.0748
0.0552	1.75270897991	378076.315105	999044.118549

WANT COPY? (1 FOR YES, 2 FOR NO)1


BLAST DOOR , 120X40 BAY, 2 in te
DISPLACEMENT
1.50
1.00
0.50
0.00
-0.50
1.00
2.00
3.30
4.00
5.00
E-2
TIME (SEC.)

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B. MAZRAS DATE: 20 SEPT 19 82 CHECKED BY: D KETCHUM DATE CHECKED: 30 SEPT 19 82

ROOF SLABS FOR THE CONCEPTUAL STRUCTURES HAVE BEEN ANALYZED WITH THE COMPUTER CODES DESCRIBED IN THE DISCUSSION OF METHODS USED AND IN APPENDIX 6. THE CODES WERE ABLE TO CALCULATE REQUIRED REBAR SIZES FOR VARYING THICKNESSES OF CONCRETE SLABS. LOADINGS ON THE SLABS WERE FROM THE TNT IMPACT CRITERIA.

WHAT FOLLOWS IS THE TABULATED RESULTS OF THESE COMPUTER RUNS. THE SLAB SIZE, DEPTH UNDER GROUND, AND THICKNESS ARE NOTED IN EACH TABLE. FOR EVERY SET OF CONDITIONS, A REQUIRED AREA OF STEEL REINFORCEMENT IS LISTED ALONG WITH A SELECTED BAR SIZE AND SPACING THAT WILL PROVIDE THAT REINFORCEMENT. A SET OF CALCULATIONS OF STIRRUP SIZE FOR A TYPICAL ROOF AND A SUMMARY ARE ALSO INCLUDED.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 2 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS - 16' BURIAL - 30" MIN THICK
BY: B. MORRIS DATE: 24 SEP 1982 CHECKED BY: DK DATE CHECKED: 24 SEPT 1982

SEE "ROOF DESIGNS", 15 SEP 82 FOR LOADINGS

25' 1-WAY $\theta = 2°$ 3' COVER

THICK (IN)	A_s (R) (IN^2/FT)	BARS	A_s (P) (IN^2/FT)	TM5-1300 MINIMUMS MAIN	TM5-1300 MINIMUMS OTHER
24	3.86	—	—	—	—
30	2.83	2-#11@12	3.12	#9@12	#6@12
36	2.20	2-#10@12	2.54		
42	1.78	2-#9@12	2.00		
48	1.50	#11@12	1.56		

54 x 37 (648" x 444") $\Delta = 7.8"$

THICK (IN)	A_s(R) LONG	BARS	A_s (P) LONG	A_s(R) SHORT $= A_s(L) \frac{54}{37} \frac{T-8}{T-6}$	BARS	A_s (P) SHORT
24	2.18	2-#10@12	2.54	2.83		
30	1.41	#11@12	1.56	1.89	2-#9@12	2.00
36	1.06	#10@12	1.27	1.44	#11@12	1.56
42	.84	#9@12	1.00	1.16	#10@12	1.27
48	.68	#8@12	.78	.95	#9@12	1.00

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS - 19' BURIAL - 2' MIN THICKNESS
BY: B. MORRIS DATE: 23 SEP 1982 CHECKED BY: DK DATE CHECKED: 24 SEP 1982

SEE SHEETS FOR 15, 20, 23 SEP FOR LOADS, Δ's

65' x 55' (780" x 660")

THICK (IN)	$A_s(R)$ LONG	BARS	$A_s(P)$ LONG	$A_s(R)$ SHORT $= A_s(L) \frac{65}{55} \frac{T-8}{T-6}$	BARS	$A_s(P)$ SHORT
24	3.55	—	—	—	—	—
30	1.94	2-#9@12	2.00	2.10	2-#10@12	2.54
36	1.37	#11 @12	1.56	1.51	#11@12	1.56

71'x46'

THICK (IN)	$A_s(R)$ LONG	BARS	$A_s(P)$ LONG	$A_s(R)$ SHORT $= A_s(L) \frac{71}{46} \frac{T-8}{T-6}$	BARS	$A_s(P)$ SHORT
24	2.65	2-#11@12	3.12	3.63	—	—
30	1.63	2-#9@12	2.00	2.31	2-#10@12	2.54
36	1.13	#10@12	1.27	1.63	2-#9@12	2.00

71x56

THICK (IN)	$A_s(R)$ LONG	BARS	$A_s(P)$ LONG	$A_s(R)$ SHORT $= A_s(L) \frac{71}{56} \frac{T-8}{T-6}$	BARS	$A_s(P)$ SHORT
24	4.00	—	—	—	—	—
30	2.04	2-#9@12	2.00	2.37	2-#10@12	2.54
36	1.36	#11@12	1.56	1.61	2-#9@12	2.00

25' 1-WAY

THICK (IN)	$A_s(R)$	BARS	$A_s(P)$
24	3.14	2-#11@12	3.12
30	2.28	2-#10@12	2.54
36	1.78	2-#9@12	2.00

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 4 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B MORRIS DATE: 23 SEP 19 82 CHECKED BY: D KETCHAM DATE CHECKED: 24 SEPT 1982

SEE "ROOF DESIGNS", 14 & 20 SEP 82

SURFACE STRUCTURES

CONCEPT 1 - 73'x60' (876"x720") PRESS = $P_o \frac{781}{73 \times 60}$ = .178 P_o

PRESS	TIME
0	0
6.2	.028
6.2	.236
32.6	.32
32.6	.377
6.2	.408
3.4	.49
0	.524

$\theta = 2°$ FDY = 72,000 f_c' = 4000

Δ = 12.6"

4" COVER LONG WAY, 3" SHORT

TM5-1300 MIN REINF.

THICK (IN)	A_s(R) LONG	BARS	A_s(P) LONG	A_s(R) SHORT = A_s(L) $\frac{73}{60}\frac{T-8}{T-6}$	BARS	A_s(P) SHORT	A_s(MIN) TM5-1300
48	1.21	#10@12	1.27	1.47	#10@10	1.52	1.33/#9@9

19' BURIAL

25' (300") 1-WAY PRESS = $\frac{10(.358P_o) + 2.5(.302P_o)}{12.5}$ = .345 P_o

PRESS	TIME
0	0
12.1	.028
12.1	.236
63.2	.32
63.2	377
12.1	.408
6.6	.49
0	.524

$\theta = 2°$ 3' COVER

THICK (IN)	A_s(R) (IN²/FT)	BARS	A_s(P) (IN²/FT)	MIN STEEL TM5-1300 MAIN		OTHER	
42	1.44	#10@10	1.52	1.14	#9@10	.50	#6@10

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 5 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: R. MORRIS DATE: 23 SEP 1982 CHECKED BY: D [illegible] DATE CHECKED: 24 SEP 1982

24' BURIAL

62'x54' (744" x 648") AREA = 3348 FT²

R INT	Δ AREA	x $\bar{P}$ =	FORCE
0-5	157	.255 P_o =	40.0 P_o
5-10	471	.22 P_o =	103.6 P_o
10-15	786	.175 P_o =	137.6 P_o
15-20	1099	.125 P_o =	137.4
20-25	3384 - 2513 = 871	x .075 P_o =	65.3 P_o
			483.9 P_o

PRESS = $\frac{483.9 P_o}{3348}$

PRESS = .145 P_o

PRESS	TIME
0	0
5.1	.028
5.1	.236
26.5	.32
26.5	.377
5.1	.408
2.8	.49
0	.524

$\Delta = \frac{1}{2}(648) \tan 2° = 11.3"$

THICK (IN)	A_s(R) LONG	BARS	A_s(P) LONG	A_s(R) SHORT $= A_s(L)\frac{62}{54}\frac{7-9}{7-6}$	BARS	A_s(P) SHORT	A_s(MIN)
30	1.57	#11@12	1.56	1.65	#10@9	1.69	.78/#8@12
36	1.17	#9@10	1.20	1.25	#10@12	1.27	.96/#9@12
42	.88	#8@10	.94	.95	#8@10	.94	1.14/#9@10

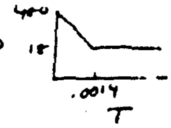
26' (312") 1-WAY - SEE PAGE 4 OF 8, 15 SEP 82 FOR PRESS

THICK (IN)	A_s(R) (IN²/FT)	BARS	A_s(P) (IN²/FT)	MINIMUM STEEL TM5-1300 MAIN		OTHER	
24	2.36	#11@8	2.34	.54	#7@12	.29	#5@12
30	1.70	#10@9	1.69	.72	#7@10	.36	#5@10
36	1.32	#9@9	1.33	.96	#9@12	.43	#6@12
42	1.07	#8@9	1.05	1.14	#9@10	.50	#6@10

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B. MORRIS DATE: 23SEP 1982 CHECKED BY: [illegible] DATE CHECKED: [illegible] 1982

71' x 46' (852" x 552") INTERNAL BLAST P



$\theta = 1°$ $\Delta = 4.8"$

THICK (IN)	A_s(R) LONG	BARS	A_s(P) LONG	A_s(R) SHORT $= A_s(L) \frac{71}{46} \frac{I=?}{J=?}$	BARS	A_s(P) SHORT	A_s(MIN)
42	.72	#7@10	.72	1.05	#8@9	1.05	1.14/#9@10
48	.60	#7@12	.60	.88	#8@10	.94	1.32/#9@9
36	.93	#8@10	.94	1.35	#9@9	1.33	.96/#9@12
30	1.36	#9@9	1.33	1.88	#11@10	1.87	.78/#9@12

24' BURIAL 40' 1-WAY - SEE 15SEP FOR PRESS

4" COVER

THICK (IN)	A_s(R) (IN^2/FT)	BARS	A_sP (IN^2/FT)
30	4.18	2-#11@9	4.16
36	3.13	2-#11@12	3.12

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COMPUTATION SHEET

SHEET NO 7 OF 13

PROJECT NO: 02-7092 SPONSOR: CERL
SUBJECT: MINIMUM REBAR PER TM 5-1300
BY: E. MORRIS DATE 20 SEP 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

Table 4-1. [illegible] Area of Flexural Reinforcement

[illegible]	[illegible]	[illegible]	[illegible]
Intermediate and low	Main Other	$A_s = 0.0025bd$ $A_s = 0.0018bd$	$A_s = 0.0025bd$ $A_s + A_s' = 0.0020bT_c$
High	Main Other	$A_s = A_s' = 0.0025bd_c$ $A_s = A_s' = 0.0018bd_c$*	$A_s = A_s' = 0.0025bd_c$ $A_s = A_s' = 0.0018bd_c$*

* [illegible]

USE INTERMEDIATE + LOW PRESSURE RANGE

MINIMUM SPACING = 9"

1-WAY ELEMENTS, 3" COVER

THICKNESS T_c (IN)	$d = T_c - 3$ (IN)	MAIN $A_s = A_s'$ (IN^2/FT)	MAIN BARS	OTHER $A_s = A_s'$ (IN^2/FT)	OTHER BARS
24	21	.63	#7@12	.29	#5@12
30	27	.81	#7@9	.36	#5@10
36	33	.99	#9@12	.43	#6@12
42	39	1.17	#9@10	.50	#6@10
60	57	1.71	#10@9	.72	#7@10
72	69	2.07	#11@9	.86	#8@10

2-WAY ELEMENTS, MAIN REINFORCEMENT ONLY

THICKNESS T_c (IN)	3" COVER $d = T_c - 3$ (IN)	3" COVER $A_s = A_s'$ (IN^2/FT)	3" COVER BARS	4" COVER $d = T_c - 4$ (IN)	4" COVER $A_s = A_s'$ (IN^2/FT)	4" COVER BARS
30	27	.81	#7@9	26	.78	#7@9
36	33	.99	#9@12	32	.96	#9@12
42	39	1.17	#9@10	38	1.14	#9@10
48	45	1.35	#9@9	44	1.32	#9@9
60	57	1.71	#10@9	56	1.68	#10@9

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SHEET NO. 8 OF 19

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS - 747 OBLIQUE IMPACT
BY: B. MORRIS DATE: 20 SEP 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

SEE "ROOF DESIGNS", 14 SEP 82, FOR LOADINGS AND OTHER CASES.

SURFACE STRUCTURES

MECH/ELEC ROOM, 73'x71' (876" x 852")

PRESS: $P_o \frac{781}{73 \times 71} = .151 P_o$

PRESS	TIME
0	0
5.3	.028
5.3	.236
27.6	.32
27.6	.377
5.3	.408
2.9	.49
0	.524

FDY = 72,000 $f_c' = 4000$

$\theta = 2°$ ⇒ $\Delta = 14.9"$

4" COVER LONG WAY, 3" COVER SHORT WAY

TM5-1300 MIN. REINF

THICK (IN)	$A_s(R)$ LONG	BARS LONG	$A_s(P)$ LONG	$A_s(R)$ SHORT $= A_s(L) \frac{73}{71} \left(\frac{T-3}{T-4}\right)$		$A_s(P)$ SHORT	$A_s(MIN)$ TM5-1300
48	1.55	#11@12	1.56	1.53	#11@12	1.56	1.32

19' BURIAL - 71'x56' SLAB AREA = 3976 FT²

R INTERVAL	ΔA	× P_{AVG}	= FORCE
0-5	157	.356 P_o	55.9 P_o
5-10	471	.302 P_o	142.2 P_o
10-15	786	.211 P_o	165.8 P_o
15-20	1099	.126 P_o	138.5 P_o
20-25	1463	.070 P_o	102.4 P_o
			604.8 P_o

AVG PRESS = $\frac{604.8 P_o}{3976}$

$= 0.152 P_o$

PRESS	TIME
0	0
5.3	.028
5.3	.236
27.6	.32
27.6	.377
5.3	.408
2.9	.49
0	.524

(852 x 672")

$\theta = 2°$ $\Delta = 11.7"$

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS - 747 OBLIQUE IMPACT
BY: B. MORRIS DATE: 20 SEP 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

THICK (IN)	$A_s(R)$ LONG	BARS LONG	$A_s(P)$ LONG	$A_s(R)$ SHORT $= A_s(L)\frac{31}{36}\frac{T-5}{T-6}$		$A_s(P)$ SHORT	$A_s(MIN)$ TMS-1300
42	1,07	#9@10	1.2	1,28	#9@9	1.33	1.14

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B. MORRIS DATE: 14 SEPT 19 82 CHECKED BY: DATE CHECKED: 19

747 OBLIQUE IMPACT - SURFACE PRESSURE

TIME	PRESS.	FORCE (LB) x 112,484 IN²	63'x40'	71'x44'
0	0	0	0	0
.028	35	3.937×10^6	10.8	8.8
.236	35	3.937×10^6	10.8	8.0
.320	183	2.058×10^7	56.7	45.7
.377	183	2.058×10^7	56.7	45.7
.408	35	3.937×10^6	10.8	8.8
.49	19	2.137×10^6	5.9	4.8
.524	0	0	0	0

FDY = 72,000 $f_c' = 4000$ $\theta = 2°$ 3" COVER - 1 WAY + 2-WAY SHORT

4" COVER - 2-WAY LONG 9" MIN BAR SPACING

63'x40' (756" x 480" x 48" DEEP) $\Delta = 8.4"$

THICK	$A_s(R)$ LONG SIDE	BARS	$A_s(P)$ LONG SIDE	$A_s(R)$ SHORT SIDE $= A_s(L)\frac{63}{40}\frac{T-8}{T-6}$		$A_s(P)$ SHORT
48	1.08	#9@10	1.20	1.80	#11@10	1.87

71'x44' (852" x 528" x 48" DEEP) $\Delta = 9.2"$

THICK	$A_s(R)$ LONG	BARS	$A_s(P)$ LONG	$A_s(R)$ SHORT $= A_s(L)\frac{71}{44}\frac{T-8}{T-6}$		$A_s(P)$ SHORT
48	1.02	#9@12	1.00	1.54	#11@12	1.56

30' 1-WAY FIXED-FIXED

THICK	$A_s(R)$ (IN²/FT)	BARS	$A_s(P)$ (IN²/FT)	TEMP. STEEL, EACH FACE *
72"	3.38	2-#10@9"	3.38	#8@10"

$* \; A_s + A_s' = .002\, b T_c = .002\,(12)(72) = 1.73 \text{ IN}^2/\text{FT}$

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SUBJECT: ROOF DESIGNS
BY: P. MORRIS DATE: 14 SEP 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

71'x46' (852"x552"x48" DEEP)

PSI 480, 18, .0014

$f_{dy} = 72,000$ $f_c' = 4000$ $\theta = 1°$, $\Delta = 4.8"$
4" COVER LONG SIDE, 3" COVER SHORT SIDE

71'x46'

THICK	A_s (R) LONG	BARS	A_s (P) LONG	A_s(R) SHORT $= A_s(L)\frac{71}{46}\frac{T-8}{T-6}$		A_s(P) SHORT
48	.60	#7@12	.60	.88	#8@10	.94

EARTH COVERED CASES

EARTH PRESSURES

235 psi

DEPTH (FT) 0

DEPTH (FT)						
5	.668	.631	.404	.73	.29	.22
10	.514	.456	.294	.125	.44	.29
15	.353	.323	.228	.125	.66	.33
20	.250	.235	.183	.118	.66	.37
25	.176	.169	.132	.95	.66	.44
$\longrightarrow$ R	0	5	10	15	20	25

AT 24' BURIAL, THE SOIL PRESSURES ARE

R(FT)	P
0	.26 P_o
5	.25 P_o
10	.19 P_o
15	.16 P_o
20	.09 P_o
25	.06

P_o = SURFACE PRESSURE

THESE PRESSURES WERE CALCULATED FOR A 22' DIAMETER CIRCULAR LOAD. THE OBLIQUE IMPACT LOADED AREA IS A 44'x22' OVAL, SO THE ABOVE PRESSURES COULD APPLY OVER RADII OF 2R, ESPECIALLY FOR A 1-WAY SLAB.

AVG. PRESS ON 40' SLAB = $\frac{10(.255 P_o) + 10(.22 P_o)}{20} = .238 P_o$

PRESS (PSI)	TIME (SEC)	FORCE ON 480"x1"
0	0	0
8.3	.028	3984
8.3	.236	3984
43.6	.32	20,928
43.6	.377	20,928
8.3	.408	3984
4.5	.49	2160
0	.524	0

40' 1-WAY SLAB FIXED - FIXED, 2", 3" COVERS

THICK (IN)	A_s (R) (IN^2/FT)	BARS	A_s (P) (IN^2/FT)	TEMP STEEL*	TEMP STEEL +
36	2.91	#11 @ 6	3.12	#5@9(.41)	#6@12(.44)
42	2.36	#11 @ 8	2.34	#6@12(.45)	#6@10(.53)
48	1.92	#11 @ 9	2.08	#6@10(.53)	#7@12(.60)
54	1.65	#10 @ 9	1.69	#6@9(.59)	#7@10(.72)

* $A_s = \frac{1}{2}(.0018)(THICK)(12)$ + TM5-1300 AS WRITTEN $A_s + A_s = .0026 T_c$

AVG PRESS ON 26' SLAB = $\frac{10(.255 P_o) + 3(.22 P_o)}{13} = .247 P_o$

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BY: B. MORRIS DATE: 15 SEP 1982 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

PRESS (PSI)	TIME (SEC)	FORCE ON 312"
0	0	0
8.6	.028	2683
8.6	.236	2683
45.2	.32	14,102
45.2	.377	14,102
8.6	.408	2683
4.7	.49	1466
0	.524	0

25' 1-WAY SLAB, FIXED, 2', 3' COVER

THICK (IN)	A_s (R) (IN^2/FT)	BARS	A_s (P) (IN^2/FT)	TEMP STEEL *	TEMP STEEL +
42	1.07	#8@9"	1.05	#5@8 (.46)	#6@10 (.53)

* $A_s = \frac{1}{2}(.0018)(THICK)(12)$
+ TM5-1300

AT 16' BURIAL

R (FT)	PRESS	ELLIPSE AREA $= 2\pi R^2$
0	$.452 P_o$	0
5	$.416 P_o$	157
10	$.298 P_o$	628
15	$.168 P_o$	1414
20	$.090 P_o$	2513
25	$.045 P_o$	

FOR A 25' 1-WAY SPAN, THE AVG PRESS COULD BE

$$P = \frac{10(.434 P_o) + 2.5(.357)}{12.5} = .419\ P_o$$

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COMPUTATION SHEET

SHEET NO. 14 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B. MORRIS DATE: 15 SEP 19 82 CHECKED BY: DATE CHECKED: 19

PRESS	FORCE ON 300"	TIME
0	0	0
14.7	4410	.028
14.7	4410	.236
76.7	23010	.32
76.7	23010	.377
14.7	4410	.408
8.0	2400	.49
0	0	.524

25' 1-WAY SLAB 1-WAY, FIXED, 3" COVER

THICK (IN)	A_s (R) (IN^2/FT)	BARS	A_s (P) (IN^2/FT)	TEMP* STEEL	TEMP STEEL +
60	1.13	#9@10	1.20	#7@10 (.72)	#9@9 (1.33)

FOR A 54X37 SLAB, AREA = 1998 FT^2

R INTERVAL	Δ AREA	FORCE = Δ AREA × $\bar{P}$
0-5'	157 ϕ	157 × .434 P_o = 68.1 P_o
5-10	471 ϕ	471 × .357 P_o = 168.1 P_o
10-15	786 ϕ	786 × .233 P_o = 183.1 P_o
15-20	1998-1414=584	584 × .129 P_o = 75.3 P_o
		494.6 P_o

$$\text{AVG PRESS} = \frac{494.6\,P_o}{1998} = \underline{.248\,P_o}$$

PRESSURE	TIME
0	0
8.7	.028
8.7	.236
45.4	.32
45.4	.377
8.7	.408
4.7	.49
0	.524

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 15 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B. MORRIS DATE: 15 SEP 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

54' x 37' (648" x 444") Δ = 7.8 4" LS. COVER

THICK (IN)	A_s (R) LONG	BARS	A_s (P) LONG	A_s (R) SHORT $= A_s(L)\frac{54}{37}\frac{T-B}{T}$		A_s (P) SHORT
60	,50	#6@10	.53	.74	#8@12	,78

TEMP STEEL = $\frac{1}{2}$(.0018)(60)(12) = .65 IN²/FT #7@10 (.72)

= 1.30 PER TM5-1300 — #9@9

19' BURIAL DEPTH

R (FT)	PRESS	AREA = $2\pi R^2$ (FT²)
0	.368 P_o	0
5	.344 P_o	157
10	.261 P_o	628
15	.162 P_o	1414
20	.090 P_o	2513
25	.049 P_o	3927

FOR A 65' x 55' SLAB; AREA = 3757

R INTERVAL	Δ AREA	Δ AREA * P_{AVG}	= FORCE
0-5	157	157 x ,356 P_o	= 55,9 P_o
5-10	471	471 x ,302 P_o	= 142,2 P_o
10-15	786	786 x .211 P_o	= 165,5 P_o
15-20	1099	1099 x .126 P_o	= 138,5 P_o
20-25	1244	1244 x .070 P_o	= 87,1 P_o
			589,5 P_o

AVG PRESS: $\frac{589,5 P_o}{3757}$ = ,157 P_o

PRESS	TIME
0	0
5,5	,028
5,5	,236
28,7	,32
28,7	,377
5,5	,408
3,0	,49
0	,524

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COMPUTATION SHEET

SHEET NO. 16 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF DESIGNS
BY: B. MORRIS DATE: 16 SEP 1982 CHECKED BY: DATE CHECKED: 19

65'x55' (780"x660") Δ = 11.5" 4" COVER LONG, 3" COVER SHORT

THICK (IN)	A_s(R) LONG	BARS	A_s(P) LONG	A_s(R) - SHORT $=A_s(L)\frac{65}{55}(\frac{T-P}{T-L})$		A_s(P) SHORT	TEMP ACI	TEMP TM5-1300
42	1.07	#8@9	1.05	1.17	#9@10	1.20	#6@10 .57	#9@10 (1,2)

FOR A 71'x46' SLAB, AREA = 3266 #

R INT	Δ AREA	Δ A * P =	FORCE
0-5	157 #	157 x .356 P_o =	55.9 P_o
5-10	471	471 x .302 P_o =	142.2 P_o
10-15	786	786 x .211 P_o =	165.8 P_o
15-20	1099	1099 x .126 P_o =	138.5 P_o
20-25	3266-2513=753	753 x .070 P_o =	52.7 P_o
			555.1 P_o

AVG PRESS = $\frac{555.1 P_o}{3266}$ = .170 P_o

PRESS	TIME
0	0
6.0	.028
6.0	.236
31.1	.32
31.1	.377
6.0	.408
3.2	.49
0	.524

71'x46' (852"x552") Δ = 9.6"

THICK (IN)	A_s(R) LONG	BARS	A_s(P) LONG	A_s(R) SHORT $=A_s(L)\frac{71}{46}\frac{T-B}{T-L}$		A_s P SHORT	TEMP ACI	TEMP TM5-1300
42	.88	#8@10	.94	1.37	#9@9	1.33	#6@10(.53)	#9@12 (1,2)

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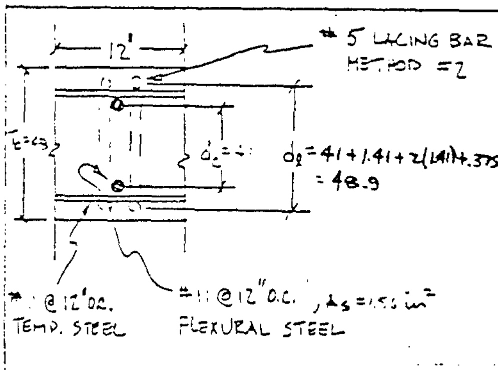
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 17 OF 18

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: STIRRUP CALCULATIONS
BY: D KETCHUM DATE: 27 Sept 19 92 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

LACING DESIGN -



$d_l = 41 + 1.41 + 2(1.41) + .375 = 48.9$

FIXED-FIXED SUPPORTS
$L = 40$ FT $= 480$ in

$M = \frac{A_s f_s d_c}{b}$

$M = \frac{1.56\,(72000)\,41}{12} = 38 \times 10^5 \frac{\text{in-lb}}{\text{in}}$

$r_u = \frac{16 M}{L^2} = \frac{16\,(38 \times 10^5)}{(480)^2} = 27$ psi

FLEX BAR, $A_s > .0025\ b d_c = .0025(12)(41) = 1.2$ in²
TEMP. BAR, $A_T > .0018\ b d_c = .0018(12)(41) = .89$ in²
A_T = #11 BAR = 1.56 in² > $A_s/2$ ✓

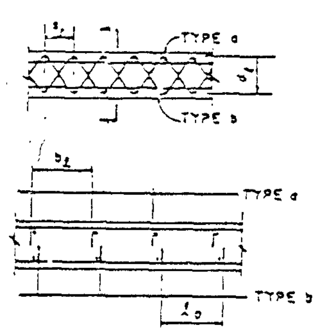
$v_u = \frac{r_u\,(\frac{L}{2} - d_c)}{d_c} = \frac{27(\frac{480}{2} - 41)}{41} = 129$ psi

$p = A_s / d_c b = \frac{1.56}{(41)(12)} = .0032$

$v_c = \phi\,(1.9\sqrt{f'_c} + 2500\,p) = .85(1.9\sqrt{4000} + 2500(.0032)) = 109$ psi

$v_{c\,max} = 2.28\,\phi\sqrt{f'_c} = 2.28\,(.85)\sqrt{4000} = 123$ psi

$V_u > V_c$ USE $V_u - V_c$ ∴ $v_u' = 20 = 20$ psi



$s_l/d_l = \frac{12}{48.9} =$, $\frac{7 D_b}{d_l} = \frac{7(.625)}{48.9} =$

FROM FIG. 6-19 OF TM5, $\alpha = 45°$

$A_d = \frac{v_u'\,s_l\,b_l}{.85\,f_s\,(\sin\alpha + \cos\alpha)} = \frac{(109)(12)(12)}{.85(60000)(\sin 45 + \cos 45)}$

$A_d = .05$ in²

USE #5 BAR

TM5-1300 REQUIRES $A_d \geq .0015\,s_l\,s_t = (.0015)(12)(12) = .216$ in²

METHOD #2

APPENDIX 6

ROOF SYSTEM COMPARISON

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DEPARTMENT [illegible]RGETIC SYSTEMS
COMP[illegible] SHEET

SHEET NO. 1 OF 1

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ROOF / 747 IMPACT CALCULATIONS
BY: B. MORRIS DATE: 27 SEPT 1982 CHECKED BY: DEK DATE CHECKED: 27 SEPT 1982

APPENDIX 6 SUMMARY

INTRODUCTION

THIS APPENDIX CONTAINS THE CALCULATIONS USED TO EVALUATE THE STRUCTURAL REQUIREMENTS OF DIFFERENT ROOF TYPES SUBJECTED TO AN OBLIQUE SURFACE IMPACT OF A 747. A 40 FOOT ONE-WAY ROOF, AN I-BEAM ROOF, AND AN ARCHED ROOF, EACH OF REINFORCED CONCRETE, ARE CONSIDERED. THE ANALYSES ALLOW A 6° ANGLE OF ROTATION AND ARE PERFORMED WITH COMPUTER CODES.

EACH ANALYSIS CONTAINS SUMMARY TABLES OF THE REQUIRED AREAS OF STEEL REINFORCING FOR VARIOUS THICKNESSES FROM A PRESSURE HISTORY OF THE IMPACT (SEE FIGURE 4.1) AND SOME BASIC DESIGN PARAMETERS. ALSO INCLUDED IN THE APPENDIX ARE A BRIEF DESCRIPTION OF THE ARCH CALCULATION METHOD, AN APPROXIMATION OF THE NATURAL FREQUENCY ACQUIRED BY THE ROOF, AND A FIGURE TAKEN FROM INTRODUCTION TO STRUCTURAL DYNAMICS BY BIGGS USED IN THE CALCULATIONS.

SOUTHWEST RESEARCH INSTITUTE
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COMPUTATION SHEET

SHEET NO. 1 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Roof Systems Comparison Calc.
BY: B. Morris DATE: 23 Sept 19 8[illegible] CHECKED BY: D Ketchum DATE CHECKED: 25 Sept 19 83

ROOF SYSTEM COMPARISON CALCULATIONS

THE ANALYSIS DETAILS WHICH FOLLOW WERE PRODUCED USING A NUMBER OF IN-HOUSE DEVELOPED COMPUTER CODES DESIGNED TO NUMERICALLY INTEGRATE THE EQUATIONS OF MOTION SUGGESTED IN BIGGS' INTRODUCTION TO STRUCTURAL DYNAMICS OR TO PERFORM OTHER MATHEMATICAL COMPUTATIONS. CODES USED ARE DESCRIBED BELOW.

'BEAMDES' — ITERATIVE DESIGN OF REINFORCED CONCRETE ONE WAY SLABS OR BEAMS SUBJECTED TO TIME-VARYING PRESSURE LOADS. IT USES BIGGS' SINGLE-DEGREE-OF-FREEDOM MODEL WITH STRUCTURAL PARAMETERS AS CALCULATED BY BIGGS OR TM5-1300.

'SLABDES' — SIMILAR TO ABOVE BUT FOR TWO-WAY REINFORCED CONCRETE SLABS.

'ARCH' — CALCULATES REACTIONS FOR FIXED-END ARCHES BASED ON ARCH SPAN, THICKNESS, AND RISE. GOVERNING EQUATIONS ARE FOUND IN FORMULAS FOR STRESS AND STRAIN BY ROARK AND YOUNG.

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COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Roof System Comparison Calc.
BY: P. Morris DATE: 27 AUG 1982 CHECKED BY: D Ketchum DATE CHECKED: 21 Sept 1982

'ONEDF' — SINGLE-DEGREE-OF-FREEDOM MAXIMUM RESPONSE OF AN UNDAMPED MASS-SPRING SYSTEM TO A SPECIFIED TIME-VARYING LOAD. EQUATIONS OF MOTION ARE FROM BIGGS.

PROJECT NO.: [illegible] SPONSOR: CERL
SUBJECT: Roof System Calcs
BY: D Ketchum DATE: 27 [illegible] 1992 CHECKED BY: DATE CHECKED: 19

ROOF SYSTEM CALCULATIONS

EACH OF THE FOLLOWING ROOF ANALYSIS IS BROKEN INTO THREE PARTS. THE FIRST IS A PRESSURE HISTORY FOR THE OBLIQUE IMPACT OF A 747 ON A CONCRETE SLAB. THIS IMPACT IS COMPLETELY DESCRIBED IN SECTION 4.1.

THE SECOND PART IS A LISTING OF THE DESIGN PARAMETERS USED. THE THIRD PART IS A SUMMARY TABLE GENERATED FROM THE AFOREMENTIONED COMPUTER PROGRAMS. THE TABLE LISTS THE REQUIRED As AND THE REBAR SIZE AND SPACING NEEDED FOR THAT AREA OF STEEL.

THE REMAINING CALCULATIONS AND TABLES SHOULD BE SELF EXPLAINATORY.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: 747 OBLIQUE IMPACT ON 40' 1-WAY ROOF
BY: B. MORRIS DATE: 27 AUG 82 CHECKED BY: DATE CHECKED: 19

PRESSURE - TIME HISTORY:

PRESSURE (PSI)	FORCE ON 1"x480" (LB)	TIME (SEC)
0	0	0
35	16,800	.028
35	16,800	.236
183	87,840	.320
183	87,840	.377
35	16,800	.408
19	9120	.49
0	0	.524

DESIGN PARAMETERS:

$\theta = 6^\circ$ $f_c' = 4000$ $f_D' = 90,000$
FIXED-FIXED SUPPORTS 3" COVER
MINIMUM BAR SPACING - 9"

THICK (IN)	A_s (REQ'D) (IN^2/FT)	BARS	A_s (PROV) (IN^2/FT)
48	6.93	—	—
54	5.95	—	—
60	5.13	—	—
72	4.01	2-#11@9	4.16
84	3.27	2-#10@9	3.38
96	2.72	2-#10@10	3.04
108	2.33	2-#9@10	2.40

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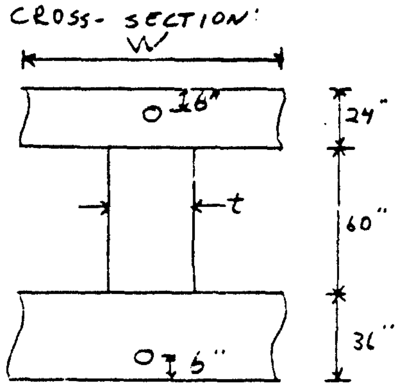
COMPUTATION SHEET

SHEET NO. 2 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: I-BEAM ROOF DESIGN
BY: B. MORRIS DATE 27 AUG 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

CROSS-SECTION:



LOADING

TIME (SEC)	P (PSI)	FORCE ON 1"x480" (LB)
0	0	0
.028	35	16800
.236	35	16800
.320	183	87840
.377	183	87840
.408	35	16800
.490	19	9120
.524	0	0

$f_c' = 4000$ $f_{dy} = 70{,}000$ $\theta = 6°$ FIXED-FIXED

REQUIRED STEEL (EACH FACE) = .1784 IN²/IN = 2.14 IN²/FT

USE #10 @ 7" A_s = 2.17 IN²/FT
OR #11 @ 8" 2.34 IN²/FT

FOR #10 @ 7, SUPPORT SHEAR = WALL REACTION = $\frac{8 A_s f_{dy}}{12} \frac{(\text{THICK}-12)}{L}$

$\boxed{\text{SUPPORT SHEAR} = 29{,}295 \text{ LB/IN}}$

ASSUME USE #5 STIRRUPS AT 6" C-C.

NOW $V_u = V_{CR} + \frac{A_v f_y d}{s}$

$$29{,}295\, W = .9\sqrt{f_c'}\; t\,(114) + \frac{(2 \times .31)(69000)(114)}{6}$$

$$29295\, W = 1.37 \times 10^4\, t + 7.07 \times 10^5$$

$$t = 2.14\, W - 51.6$$

t (IN)	W (IN)	W/t	CLEAR SPACE BETWEEN WEBS (IN)
6	26.9	4.48	21
12	29.7	2.43	18
18	32.5	1.81	15

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ARCHES
BY: B Morris DATE: 18 Aug 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

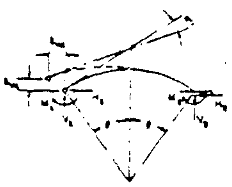
REFERENCE: FORMULAS FOR STRESS AND STRAIN, 5th EDITION
ROARK + YOUNG, McGRAW HILL, 1975

TABLE 18 *Reaction and deformation formulas for circular arches*

NOTATION: W = load (pounds), w = unit load (pounds per linear inch), M_o = applied couple (inch-pounds), θ_o = externally created concentrated angular displacement (radians), Δ_o = externally created concentrated lateral displacement (inches), $T - T_o$ = uniform temperature rise (degrees), T_1 and T_2 = temperatures on outside and inside, respectively (degrees). H_A and H_B are the horizontal end reactions at the left and right, respectively, and are positive to the left (pounds). V_A and V_B are the vertical end reactions at the left and right, respectively, and are positive upward (pounds). M_A and M_B are the reaction moments at the left and right, respectively, and are positive clockwise (inch-pounds). I is the area moment of inertia for bending in the plane of the arch.

The axial stress deformation factor is $\alpha = I/AR^2$, where A is the cross-sectional area. The transverse shear deformation factor is $\beta = FEI/GAR^2$, where G is the shear modulus of elasticity and F is a shape factor for the cross section (see page 185). R = arch radius; $s = \sin\theta$; $c = \cos\theta$; $n = \sin\phi$, and $m = \cos\phi$; γ = temperature coefficient of expansion (inches per inch per degree).

General reactions and deformation expressions for cases 1 to 14, right end fixed in all 14 cases.



Deformation equations:

$$\text{Horizontal deflection at } A = \delta_{HA} = \frac{R^3}{EI}\left(A_{HH}H_A + A_{HV}V_A + A_{HM}\frac{M_A}{R} - LF_H\right) \quad (3)$$

$$\text{Vertical deflection at } A = \delta_{VA} = \frac{R^3}{EI}\left(A_{VH}H_A + A_{VV}V_A + A_{VM}\frac{M_A}{R} - LF_V\right) \quad (4)$$

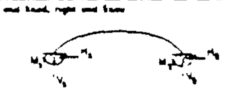
$$\text{Angular rotation at } A = \psi_A = \frac{R^2}{EI}\left(A_{MH}H_A + A_{MV}V_A + A_{MM}\frac{M_A}{R} - LF_M\right) \quad (5)$$

where $A_{HH} = \theta + 2\theta c^2 - 3sc + \alpha(\theta + sc) + \beta(\theta - sc)$
$A_{HV} = A_{VH} = 2s^2 - 2\theta s$ [illegible]
$A_{HM} = A_{MH} = 2s - 2\theta c$
$A_{VV} = \theta + 2\theta s^2 - sc + \alpha(\theta - sc) + \beta(\theta + sc)$
$A_{VM} = A_{MV} = 2\theta s$
$A_{MM} = 2\theta$

and where LF_H, LF_V, and LF_M are loading terms given below for several types of load

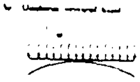
(Note: If desired, H_B, V_B, and M_B can be evaluated from equilibrium equations after calculating H_A, V_A, and M_A)

1. Left end fixed, right end fixed



Since $\delta_{HA} = 0$, $\delta_{VA} = 0$, and $\psi_A = 0$, Eqs. 3 to 5 must be solved simultaneously for H_A, V_A, and M_A/R. The loading terms are given below.

[illegible] Uniform vertical load



$LF_H = wR$ [illegible]

$LF_V = wR$ [illegible]

$LF_M = wR$ [illegible]

THESE EQUATIONS HAVE BEEN PROGRAMMED IN "ARCH" WITH THE FOLLOWING RESULTS

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 2 OF 2

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ARCHES
BY: B. MORRIS DATE: 18 AUG 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

40' SPAN, 1" WIDE SECTION

RISE (INCHES)	THICKNESS (IN)	HA (LB)	VA (LB)	MA (LB-IN)	Mc (LB-IN)	Hc (LB)
60	24	-396 w	240 w	-3084 w	1956 w	-396 w
	36	-317 w	240 w	-6249 w	3531 w	-317 w
	48	-240 w	240 w	-9337 w	5063 w	-240 w
	60	-173 w	240 w	-12,000 w	6420 w	-173 w
120	24	-228 w	240 w	54 w	1494 w	-228 w
	36	-206 w	240 w	-1686 w	2394 w	-206 w
	48	-179 w	240 w	-3805 w	3515 w	-179 w
	60	-150 w	240 w	-6097 w	4703 w	-150 w
230	24	-135 w	240 w	5025 w	2775 w	-135 w
	36	-130 w	240 w	4258 w	3158 w	-130 w
	48	-123 w	240 w	3238 w	3748 w	-123 w
	60	-114 w	240 w	2014 w	4594 w	-114 w

w = UNIFORM VERTICAL LOAD

M_c = MOMENT AT CROWN, H_c = THRUST AT CROWN
V_c = SHEAR AT CROWN = 0.

ASSUME M_c IS POSITIVE COUNTER CLOCKWISE

$$\Sigma M_c = 0 \Rightarrow M_c - RISE * H_A - M_A - \frac{SPAN}{2} V_A + w \frac{SPAN}{2} \times \frac{SPAN}{4} = 0$$

$$M_c - RISE(H_A) - M_A - 240 V_A + 28{,}800 w = 0$$

$$\boxed{M_c = M_A + 240 V_A + RISE \cdot H_A - 28800 w} \quad +\circlearrowleft$$

$\boxed{H_c = H_A}$ + TO THE RIGHT

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF 4

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ARCH ROOF DESIGN
BY: E. MORRIS DATE: 19 AUG 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

USE THE 747 OBLIQUE IMPACT, UNMOUNDED

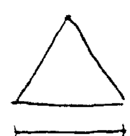
TIME	PRESSURE (PSI)	FORCE	TOTAL IMPULSE
0.	0	0	0
.028	35	.168 $\times 10^5$	235
.236	35	.168	3727
.320	183	.878 $\times 10^5$ = F1	8123
.377	183	.878	13,128
.408	35	.168	14,749
.490	19	.091	15,811
.524	0	0	15966

FLAT ROOF DESIGN

THICK (IN)	A_s (in²/ft)	NATL PERIOD	Δ_y	$\mu = \frac{\Delta}{\Delta_y}$	R_m	$\frac{R_m}{F_1}$
36	9.06	.0551	3.5"	14.6	.68 $\times 10^5$	.77
48	6.00	.0430	1.48	34.5	.63 $\times 10^5$	.72
60	4.38	.0361	.78	65.4	.59 $\times 10^5$	.67

BY .408 SEC, THE SYSTEM HAS REACHED MAX RESPONSE.
TREAT THE LOAD AS A TRIANGLE

F



t_d

$I = \frac{1}{2} F_1 t_d = \frac{1}{2} (.878 \times 10^5) t_d = 14,749$

$\boxed{t_d = .336 \text{ SEC}}$

USE FIG 2.26 IN BIGGS TO CHECK RESPONSE:

THICK	$\frac{t_d}{T}$	$\frac{R_m}{F_1}$	μ	CLOSENESS
36	6.1	.77	≈13	OK
48	7.8	.72	≈35	REAL GOOD
60	9.3	.67	≈80	MODERATELY OK

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: ARCH ROOF DESIGN
BY: B. MORRIS DATE: 19 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

CONSIDER THE 40' SPAN, 5' RISE ARCH. BIGGS GIVES AN APPROXIMATION TO THE NAT'L PERIOD FOR AN ARCH IN RADIAL COMPRESSION AS

$$T_c = \frac{R}{1610} = \frac{42.5}{1610} = .0235 \text{ SEC.}$$

SINCE WE DON'T HAVE TRUE RADIAL COMPRESSION, ASSUME NAT'L PERIOD IS BETWEEN THIS AND THE FLAT ROOF VALUE.

USE

ARCH THICK	NAT'L PERIOD	$\frac{t_d}{T}$
36	.0393	8.5
48	.0332	10.1
60	.0298	11.3

ASSUME WANT SAME μ'S AS CALCULATED FOR THE 36" AND 48" CASES

ARCH THICK	μ
36	15
48	35

FROM BIGGS FIGURE 2.26, FIND $\frac{R_m}{F_1}$
(SEE PAGE 4 OF THIS WRITE-UP)

ARCH THICK	μ	$\frac{t_d}{T}$	$\frac{R_m}{F_1}$	R_m
36	15	8.5	.8	70,420
48	35	10.1	.75	65,850

COMPARE SUPPORT MOMENTS FOR FLAT AND ROOF

SECTION THICK	ARCH MOMENT	FLAT MOMENT	$\frac{FLAT}{ARCH}$
36	6249 w	19200 w	3.08
48	9337 w	19200 w	2.06

w = APPLIED UNIFORM VERT. LOAD.

FOR THE FLAT, $R_m(\text{FLAT}) = \frac{16\,M}{L}$, M = MOMENT CAPACITY OF THE CROSS-SECTION

USE $R_m(\text{ARCH}) = R_m(\text{FLAT}) \times \left(\frac{\text{FLAT}}{\text{ARCH}}\right) = \frac{16\,M}{L}\left(\frac{\text{FLAT}}{\text{ARCH}}\right)$

THUS, $M(\text{ARCH}) = M(\text{FLAT}) \frac{\text{ARCH}}{\text{FLAT}}$

MOMENT CAP = A_s FDY (THICK − 6)

THUS, $A_s(\text{ARCH}) = A_s(\text{FLAT})\left(\frac{\text{ARCH}}{\text{FLAT}}\right)$ FOR OTHER CONDITIONS CONSTANT

THICK	A_s (FLAT) (IN^2/FT)	A_s (ARCH) (IN^2/FT)
36	6.00	1.95
48	4.38	2.13

CONCLUSION: WHILE SOME STEEL SAVINGS MAY BE POSSIBLE, THE COST OF FABRICATION PLUS THE NEED FOR IMPROVED WALL DESIGN TO TAKE THE ARCH THRUST WILL OFFSET ANY SAVINGS.

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Arch Roof Design
BY: DATE: 19 CHECKED BY: DATE CHECKED: 19

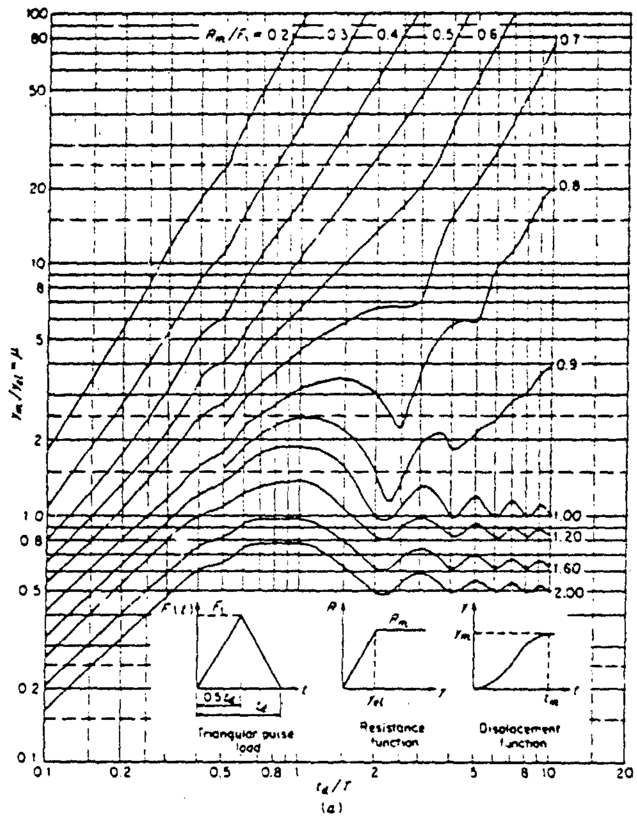

FIGURE 2.26 Maximum response of elasto-plastic one-degree systems (undamped) due to equilateral triangular load pulses.

APPENDIX 7

DIVIDING WALL COMPARISON

Appendix 7: Dividing Wall Comparisons Calculations

This appendix contains the calculation work sheets for

blast loads,
fragment threat analysis,
spall analysis,
and design for interior dividing walls.

The blast loads were determined for a 1'x5' wall panel with a 78.5 lb charge on the floor 3.5' from the wall.

For the fragment threat analysis, a worst case steel cube fragment weighing 0.4 lb having an impact velocity of 3000 ft/sec, was used to calculate depth of penetration into concrete, steel, spaced armor and sand. The penetration depths calculated were used to specify wall thicknesses necessary to contain the worst case fragment threat.

The spall analysis work sheets are included to show how calculations of spalling and spall velocity were made.

Work sheets are included for design calculations for a concrete cantilever wall, a steel suppressive shield type wall, a wall consisting of two steel sections with sand in between

the steel sections, and a steel/concrete composite wall. The thicknesses and construction descriptions for each wall type are indicated in the work sheets.

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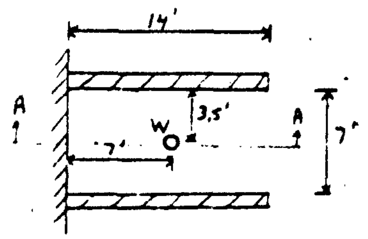
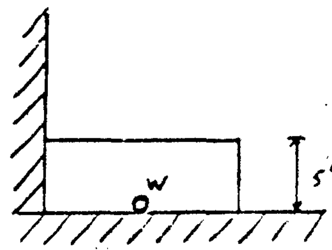
COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: BLAST LOADS ON INTERIOR DIVIDING WALLS
BY: B. MORRIS DATE 22 JUL 1983 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

7.1 Blast Loads





CHARGE WT = 78.5# BUT DOUBLE SINCE ITS ON THE FLOOR

$\boxed{W_e = 157 \text{ LB}}$

SwRI has developed a small computer program to predict wall blast loading
FROM PROGRAM INPUT ATTACHED AS PAGE 7-5,

$P_{max} = 15{,}000$ PSI

$i = 1.05$ PSI-SEC

$T_D = \frac{2i}{P} = .00014$ SEC

MULTIPLY THIS PRESSURE AND IMPULSE BY 1.75 TO ACCOUNT FOR REFLECTIONS WITHIN THE STORAGE AREA (PER DOE/TIC-11268)

$P = 26{,}250$ PSI

$i = 1.84$ PSI-SEC

$T_D = .00014$ SEC

QUASI-STATIC PRESSURES WILL NOT EFFECT THE WALLS SINCE THEY WILL ACT ON BOTH SIDES.

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COMPUTATION SHEET

SHEET NO. ____ OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT: [illegible] Wall

BY: NRS DATE: [illegible] 19 82 CHECKED BY: ____ DATE CHECKED: ____ 19 ____

1' × 5' wall panel $R = 3.5'$ $w = 157$
charge on floor

$w^{1/3} = 5.39$

$R/w^{1/3} = 0.649 \ ft/lb^{1/3}$

$i_{spimp} = 1.05$ psi - sec

$i/w^{1/3} = 0.19 \ \frac{psi-sec}{lb^{1/3}}$

$x/R = .7$

Pressure = 15,000 psi

1.5

INPUT PARAMETERS:

CHARGE WEIGHT =	157.00 LB
PERPENDICULAR STANDOFF =	3.50 FT
PLATE LENGTH, XTOT =	1.00 FT
PLATE WIDTH, YTOT =	5.00 FT

CHARGE POSITION IN PLANE PARALLEL TO PLATE

LENGTHWISE DISTANCE FROM PLATE CORNER, XC =	0.50 FT
WIDTHWISE DISTANCE FROM PLATE CORNER, YC =	0.00 FT

OUTPUT:

TOTAL APPLIED IMPULSE = 0.7544E+03 LB-SEC

AVERAGE SPECIFIC IMPULSE = 1.05 PSI-SEC

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 1 OF

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FRAGMENT THREAT ANALYSIS
BY: LMV DATE: 8/3 19 82 CHECKED BY: DATE CHECKED: 19

7.2 FRAGMENT THREAT ANALYSIS:

ASSUME A WORST CASE STEEL FRAGMENT WEIGHING 0.4 lbs, IN SHAPE OF A CUBE, WITH AN L/D RATIO CLOSE TO 1.0 AND AN IMPACT VELOCITY OF 3000 fps.

7.2.1 CALCULATE DEPTH OF PENETRATION INTO CONCRETE

MODIFIED NDRC EQUATION FOR DEPTH OF PENETRATION "X"

$$G(x/d) = \alpha K N \frac{W}{d} \left(\frac{V}{1000 d}\right)^{1.8}$$

WHERE:

α = CONSTANT = 1.0

N: MISSILE SHAPE FACTOR = 0.72

$$K = \frac{180}{\sqrt{f'_c}} \left(\frac{E}{29{,}000}\right)^{1.25}$$

E = MODULUS OF ELASTICITY OF MISSILE IN Kips/in²
E = 30 000 Kips/in²
f'_c = 4000 psi

K = 2.97

W = MISSILE WEIGHT (lbs)

V = IMPACT VELOCITY (fps)

d = MISSILE DIAMETER (in)

a) CALCULATE MISSILE DIAMETER. A CUBE STEEL FRAGMENT WEIGHING 0.4 lbs, CALCULATE THE PRESENTED AREA

$\rho \, Vol = W$

$Vol = W/\rho = 0.4 \text{ lbs} / 0.283 \text{ lbs/in}^3$

VOLUME = 1.413 in³

AREA = 1.259 in²

CONVERT THE PRESENTED AREA OF THE CUBE (1.259 in²) TO A PRESENTED AREA OF A CYLINDER AND DETERMINE THE DIAMETER d.

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FRAGMENT THREAT ANALYSIS
BY: LMV DATE: 8/3 19 82 CHECKED BY: DATE CHECKED: 19

$A_{cyl} = \frac{\pi d^2}{4} = 1.259 \text{ in}^2$

$d = 1.266$ in

b) SOLVE MODIFIED NDRC EQUATION FOR DEPTH OF PENETRATION "X"

$G(x/d) = \alpha K N \frac{w}{d} \left(\frac{V}{1000 d}\right)^{1.8}$

$G(x/d) = (1.0)(0.72)(2.97)\left(\frac{0.4}{1.266}\right)\left(\frac{3000}{1266}\right)^{1.8}$

$G(x/d) = 3.19$

$G(x/d) = \frac{x}{d} - 1 \qquad \text{for } \frac{x}{d} \geq 2.0$

$\therefore \quad \frac{x}{d} - 1 = 3.19$

$\frac{x}{d} = 4.19$

$x = 5.30$ in.

c) SOLVE MODIFIED NDRC EQUATION FOR DEPTH TO PREVENT PERFORATION "e"

$\frac{e-a}{d} = 1.32 + 1.24\left(\frac{x}{d}\right) \qquad \text{for } 3 \leq \frac{e}{d} \leq 19$

a = MAX. AGGREGATE SIZE = 1.5 in

$\frac{e - 1.5}{1.266} = 1.32 + 1.24(4.19)$

$e = 9.75$ in.

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COMPUTATION SHEET

SHEET NO. 3 OF

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FRAGMENT THREAT ANALYSIS
BY: LMV DATE: 2/3 19 82 CHECKED BY: DATE CHECKED: 19

1.2.2 CALCULATE DEPTH OF PENETRATION INTO STEEL

THOR EQUATION FOR BALLISTIC PROTECTION VELOCITY (V_0)

$$V_0 = 10^{C_1} (tA)^{\alpha_1} (7000 W_s)^{\beta_1} (\sec\theta)^{\gamma_1}$$

Where:

t = TARGET THICKNESS IN INCHES.

A - AVERAGE IMPACT AREA OF THE FRAGMENT IN SQUARE INCHES.

W_s = WEIGHT OF THE ORIGINAL FRAGMENT IN lbs.

θ = IMPACT ANGLE (DEGREES)

$C_1, \alpha_1, \beta_1, \gamma_1$ = EMPIRICAL CONSTANTS DEPENDANT ON TARGET MAT'L

SOLVE THOR EQUATION FOR t.

$V_0 = 3000$ fps

$A = 1.259$ in^2

$W_s = 0.4$ lb

$\theta = 0°$

$C_1 = 6.523$ for MILD HOMOG. STEEL

$\alpha_1 = 0.906$ for MILD HOMOG. STEEL

$\beta_1 = -0.963$ for MILD HOMOG. STEEL

$\gamma_1 = 1.286$ for MILD HOMOG. STEEL

$$(tA)^{\alpha_1} = V_0 / 10^{C_1} (7000 W_s)^{\beta_1} (\sec\theta)^{\gamma_1}$$

$$t = \left[V_0 / 10^{C_1} (7000 W_s)^{\beta_1} (\sec\theta)^{\gamma_1} \right]^{1/\alpha_1} \Big/ A$$

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 4 OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT: FRAGMENT THREAT ANALYSIS

BY: LMV DATE: 8/13 19 82 CHECKED BY: ________ DATE CHECKED: ________ 19 ____

$$t = \left[3000 / 10^{6.523} (7000 \cdot 0.4)^{-0.963} (\sec 0)^{1.286} \right]^{1/.906} / 1.259$$

$$t = \left[3000 / (3.334 \times 10^{6})(4.79 \times 10^{-4}) \right]^{1/.906} / 1.259$$

$$t = (1.878)^{1.104} / 1.259$$

$$t = 1.59 \text{ inches}$$

∴ A STEEL PLATE 1.59 INCHES WILL DEFEAT A STEEL CUBE WEIGHING 0.4 lbs, AT 3000 fps.

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FRAGMENT THREAT vs SPACED ARMOR
BY: LMV DATE: 8/4 1982 CHECKED BY: DATE CHECKED: 19

1.2.3 CALCULATE DEPTH OF PENETRATION INTO SPACED ARMOR

$$V_R = V_S - 10^c (tA)^{\alpha} (7000\, W_S)^{\beta} V_S^{\lambda}$$

1/2 in Homog. Steel

$c = 6.399$ $t = .8$ in
$\alpha = .889$ $A = 1.259$ in^2
$\beta = -.945$ $W_S = 0.4$ lb
$\lambda = .019$ $V_S = 3000$ fps

$$V_S^{\lambda} = 3000^{.019} = 1.1643$$

$$(7000\, W_S)^{\beta} = (7000(.4))^{-.945} = .0005526$$

$$10^c = 10^{6.399} = 2.5 \times 10^6$$

$$(tA)^{\alpha} = (.8(1.259))^{.889} = 1.0064$$

$$V_R = V_S - 1618.8$$

$$V_R = 1381.2 \text{ fps}$$

Calculate Thickness To Stop Frag. with Impact Vel - 1381 fps. Assume No Mass Loss After 1st Impact, Normal Impact

$$V_0 = 10^{c_1} (tA)^{\alpha_1} (7000\, W_S)^{\beta_1}$$

$$tA^{\alpha_1} = V_0 / 10^{c_1} (7000\, W_S)^{\beta_1}$$

$$t = \frac{1}{A} \left[V_0 / 10^{c_1} (7000\, W_S)^{\beta_1} \right]^{1/\alpha_1}$$

$c_1 = 6.523$ $A = 1.259$ in^2
$\alpha_1 = 0.906$ $V = 1381$ fps
$\beta_1 = -0.963$

$$t = \frac{1}{1.259} \left[1381 / 3334260 (.0004791) \right]^{1/.906} = 1.103758$$

$t = .676$ in.

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SHEET NO. 6 OF ____

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: FRAGMENT PENETRATION INTO STEEL
BY: LMV DATE: 8/4 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

FRAGMENT PENETRATION INTO STEEL - PANTEX MANUAL - 6.4.1.1

ASSUME FRAGMENT IS A SPHERE

$$\frac{4}{3}\pi r^3 \rho = W_T$$

$$\pi r^3 = 0.4/.283 \left(\frac{3}{4}\right)$$

$$r = 0.695 \text{ in.} = a$$

$V_{50} = 3000$ fps
$\rho_P = .283$ lb/in^3
$\rho_t = .283$ lb/in^3
$\sigma_t = 36 \times 10^3$ psi

$$\frac{V_{50}\ \rho_P}{\sqrt{\sigma_t\ \rho_t}} = 8.4$$

FROM FIG. 6 21, $\frac{h}{a} = 2.1$, $a = 0.695$ in

$$h = 1.46 \text{ in.}$$

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COMPUTATION SHEET

SHEET NO. 7 OF

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Fragment Threat Analysis
BY: TKM DATE: 8/3 19 82 CHECKED BY: DATE CHECKED: 19

7.2.4 CALCULATE DEPTH OF PENETRATION INTO SAND

Figure 1 from TM5-1300 is used.

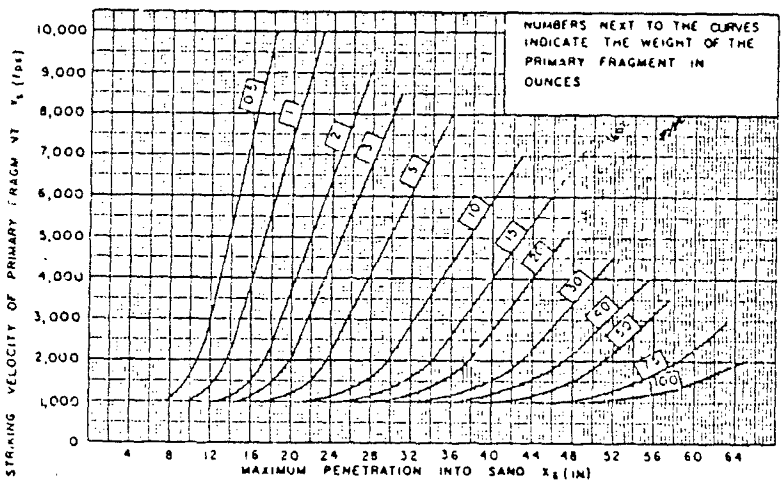

Figure 1

Steel fragment weight = 0.4 lb = 6.4 oz
Striking velocity = 3000 ft/sec

Interpolating from the figure for a weight of 6.4 oz yields a maximum penetration into sand of

26-28 inches.

7.3 SPALL ANALYSIS

7.3.1 DETERMINE WHETHER SPALL WILL OCCUR

f'_c = 4000 psi

σ_u = 320 psi

H = wall thickness = 12"

E = 2 x 10^6 lb/in²

ρ = 2.25 x 10^{-4} $\frac{lb\,sec^2}{in^4}$

Input parameters from blast loads.

P_r = 14,175 psi

i_r = 1.3 psi-sec.

Using Figure 1 from DOE/TIC 11268, determine whether or not spalling will occur on the backface of a dividing wall which has been loaded by blast from the detonation of a explosive inside a bay.

First calculate the stress wave velocity, v, through the wall:

$$v = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{2\times10^6 \frac{lb}{in^2}}{2.25\times10^{-4}\frac{lb\,sec^2}{in^4}}} = 94280 \frac{in}{sec} = 7862 \frac{ft}{sec}$$

$$\frac{i_r v}{P_r H} = \frac{(1.3\ psi\text{-}sec)(94280\ in/sec)}{(14175\ psi)(12\ in)} = 0.72$$

$$\frac{P_r}{\sigma_u} = \frac{14175\ psi}{320\ psi} = 44$$

Using Figure 1 we determine that backface spalling will occur.

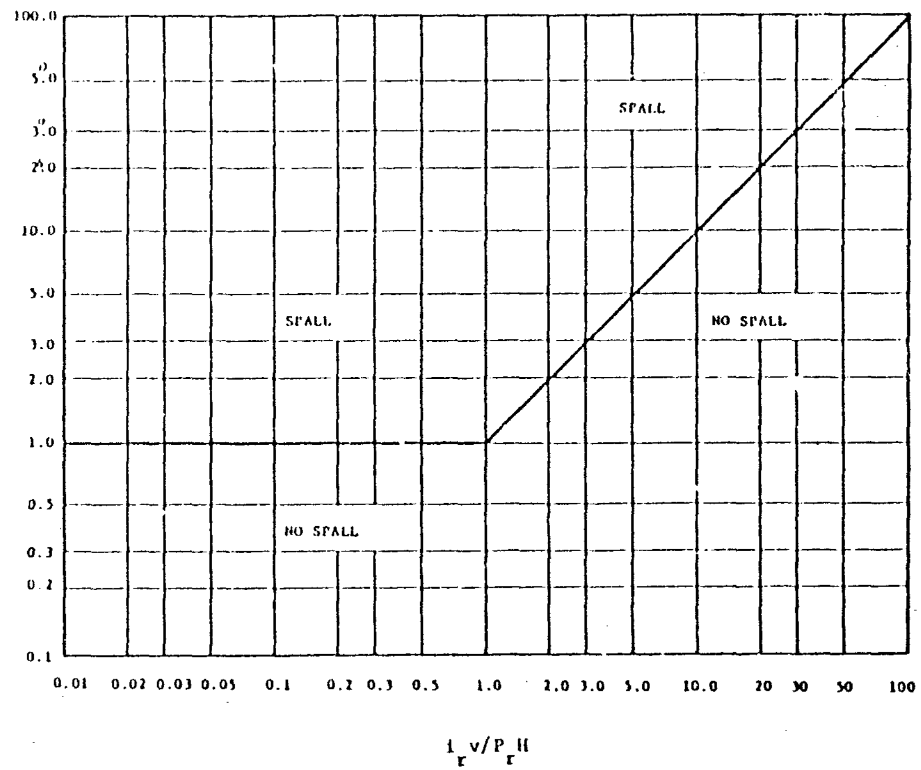

Figure 1 . Spall Threshold for Blast Waves Loading Walls

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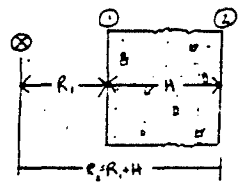
SHEET NO. 1 OF 1

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Spall Velocity Calculation for Dividing Wall
BY: TKM DATE: 3 Sep 1982 CHECKED BY: DATE CHECKED: 19

7.3.2 DETERMINE SPALL VELOCITY $R = 3.5'$

First attenuate i_{r_1} linearly through the wall to obtain estimate at backface of wall, i_{r_2}.



$$i_{r_2} = i_{r_1} \frac{R_1}{(R_1+H)} = (1.3\,\text{psi-sec})\left(\frac{3.5'}{3.5+1'}\right)$$

$$= 1.01\,\text{psi-sec}$$

Now determine a spall velocity for a 3"x3"x3" chunk of spall.

Area $A = 9\,in^2$

Impulse $i_{r_2} = 1.01\,\text{psi-sec}$

Mass $m = (27\,in^3)(2.3\times10^{-4}\,\frac{lb\,sec^2}{in^4}) = 6.2\times10^{-3}\,\frac{lb\,sec^2}{in}$

Velocity, then, is

$$u = \frac{i_{r_2} A}{m} = \frac{(1.01\,\text{psi-sec})(9\,in^2)}{(6.2\times10^{-3}\,\frac{lb\,sec^2}{in})} = 1466\,\frac{in}{sec} = 122\,\frac{ft}{sec}$$

$$\simeq \boxed{120\,\frac{ft}{sec}}$$

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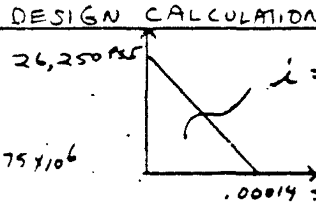
SHEET NO. 1 OF

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: DIVIDING WALL DESIGN
BY: L. MORRIS DATE 22 JUL 19 82 CHECKED BY: DATE CHECKED: 19

7.4 DIVIDING WALL DESIGN CALCULATIONS

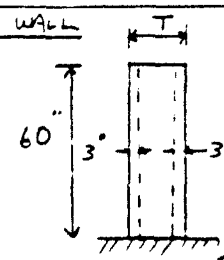
PRESSURE-TIME



$i = 1.84$ PSI-SEC

FORCE $= 60 \times 26,250 = 1.575 \times 10^6$

7.4.1 DESIGN FOR CONCRETE CANTILEVER WALL



Steel area is A_s EACH FACE

$f_c' = 4000$ PSI
$f_{dy} = 90,000$ PSI
$\theta = 12°$

T (IN)	A_s (IN²/FT)	FLOOR REACTION (LB/IN)	SHEAR STRESS IN WALL = $\frac{REACTION}{T-6}$
12	3.38	5070	845 PSI
15	1.77	3982	442
18	1.12	3360	280
21	.78	2925	195
24	.56	2526	140

FOR CANTILEVERS, (TM 5-1300, TABLE 5-5) $r_u = \frac{2M_N}{L^2}$

(TM 5-1300, TABLE 5-12) SUPPORT SHEAR $V_s = r_u L$

$\therefore V_s$ = FLOOR REACTION $= \frac{2M_N}{L} = \frac{2\frac{A_s}{12}(F_{DY})(T-6)}{L}$

$V_s = \frac{A_s F_{DY}(T-6)}{6L}$

SHEAR STRENGTH OF CONCRETE (TM5-1300) $\leq 2.28(.85)\sqrt{f_c'}$
$\leq 2.28(.85)\sqrt{4000} = 123$ PSI $= v_c$

NOW DETERMINE STEEL AREAS REQUIRED TO PROVIDE SUPPORT STRENGTH.

$A_v = \frac{12''(\text{TOTAL REACTION} - v_c(T-6))}{75,000}$ IN²/FT

7-17 $\hookrightarrow 75,000 = \frac{1}{2}(f_y + f_u) = \frac{1}{2}(60,000 + 90,000)$

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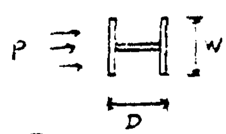
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: DIVIDING WALL DESIGN
BY: B. MORRIS DATE: 22 JUL 19 82 CHECKED BY: ___ DATE CHECKED: ___ 19 ___

I	REACTION	A_v (IN²/FT)
12	5070	.69
15	3982	.46
18	3360	.30
21	2925	.17
24	2520	.05

7.4.2 DESIGN FOR STEEL SUPPRESSIVE SHIELD TYPE WALL

CONSIDER AN INTERLOCKING I-BEAM SYSTEM



$\theta = 12°$
FDY = 60,000 - 1.2×50,000
L = 60" ASSUME 30#/FT SO WT = 150#

USE A SPECIAL-PURPOSE PROGRAM DEVELOPED AT SwRI WHICH CALCULATES THE MINIMUM ELASTIC + PLASTIC SECTION MODULUS TO RESIST THE APPLIED LOADS.

W(IN)	D(IN)	REQ'D S (IN³)	Z	SECTION
6	6	33.98	38.74	
	9	33.98	38.74	
	12	32.91	37.52	
4	4	15.29	17.43	
	8	14.75	16.82	
	12	14.75	16.82	12×4 B (16.5)
5	5	23.30	26.56	
	12	23.30	26.56	$\boxed{12 I 5 \; (31.8 \; \#/ft)}$
7	7	45.73	52.14	
	12	45.73	52.14	

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SHEET NO. 3 OF 5

PROJECT NO.: 02 7092 SPONSOR: CERL
SUBJECT: DIVIDING WALL DESIGN
BY: B Morris DATE: 23 Sept 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

NOW VARY BEAM WEIGHT / FT WITH LESS D VARIATION

WT/FT (LB)	W (IN)	D (IN)	S (IN^3)	Z (IN^3)	POSSIBLE SECTIONS PER 1973 AISC MANUAL
40	4	4	11.55	13.16	
		12	11.01	12.55	
	5	5	17.96	20.47	
		12	17.42	19.86	S 12 x 40.8 (Z=57.1)
	6	6	25.44	29.00	
		12	25.44	29.00	S 15 x 42.9 (Z=69.3)
30	4	4	15.29	17.43	
		12	14.75	16.82	
	5	5	23.30	26.56	
		12	23.30	26.56	S 12 x 31.8 (Z=42.0)
	6	6	33.98	38.74	W 12 x 27 (Z = 38.0)
		12	32.91	37.52	W 10 x 29 (Z = 34.7)
20	4	4	23.30	26.56	W 12 x 22 (Z = 29.3)
		12	22.23	25.34	
	5	5	35.05	39.96	
		12	35.05	39.96	W 14 x 26 (Z = 40.0)
	6	6	50.01	57.01	
		12	50.01	57.01	
15	4	4	30.78	35.09	
		12	29.71	33.87	
	5	5	47.87	54.57	
		12	45.73	52.14	
	6	6	67.10	76.50	
		12	67.10	76.50	

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SHEET NO. 4 OF 5

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: DIVIDING WALL DESIGN
BY: Morris DATE: 23 Jun 1983 CHECKED BY: ________ DATE CHECKED: ______ 19__

WT/FT (LB)	W (IN)	D (IN)	S (IN^3)	Z (IN^3)	
50	4	12	8.34	9.51	
	5	12	13.15	14.99	
	6	12	19.49	21.08	
	8	12	32.91	37.52	W 14x48 (Z = 78.4)
40	8	12	44.67	50.92	W 10x45 (Z=54.9) W 12x40 (Z=57.5)
30	8	12	58.55	66.75	
20	8	12	88.47	100.85	
15	8	12			

NOW DETERMINE THE TOTAL STEEL PER FOOT OF DIVIDING WALL FOR SOME OF THESE SECTIONS.

SECTION	WT/FT x (5 FT HEIGHT)	x $\left(12 \frac{IN}{FT} \times \frac{1\,FT}{W}\right)$	= WT/FT OF WALL
12 I 5	31.8 x 5	x $\frac{12}{5}$	= 382 LB
S12x40.8	40.8 x 5	x $\frac{12}{5}$	= 490
S15x42.9	42.9 x 5	x $\frac{12}{6}$	= 429
W12x27	27 x 5	x $\frac{12}{6}$	= 270
W14x26	26 x 5	x $\frac{12}{5}$	= 312

NOW DETERMINE CONCRETE WTS

THICKNESS (IN)	$\frac{T}{12} \times 5 \times 150 = \frac{WT}{FT\ OF\ WALL}$
12	1 x 5 x 150 = 750 LB
15	= 938
18	= 1125

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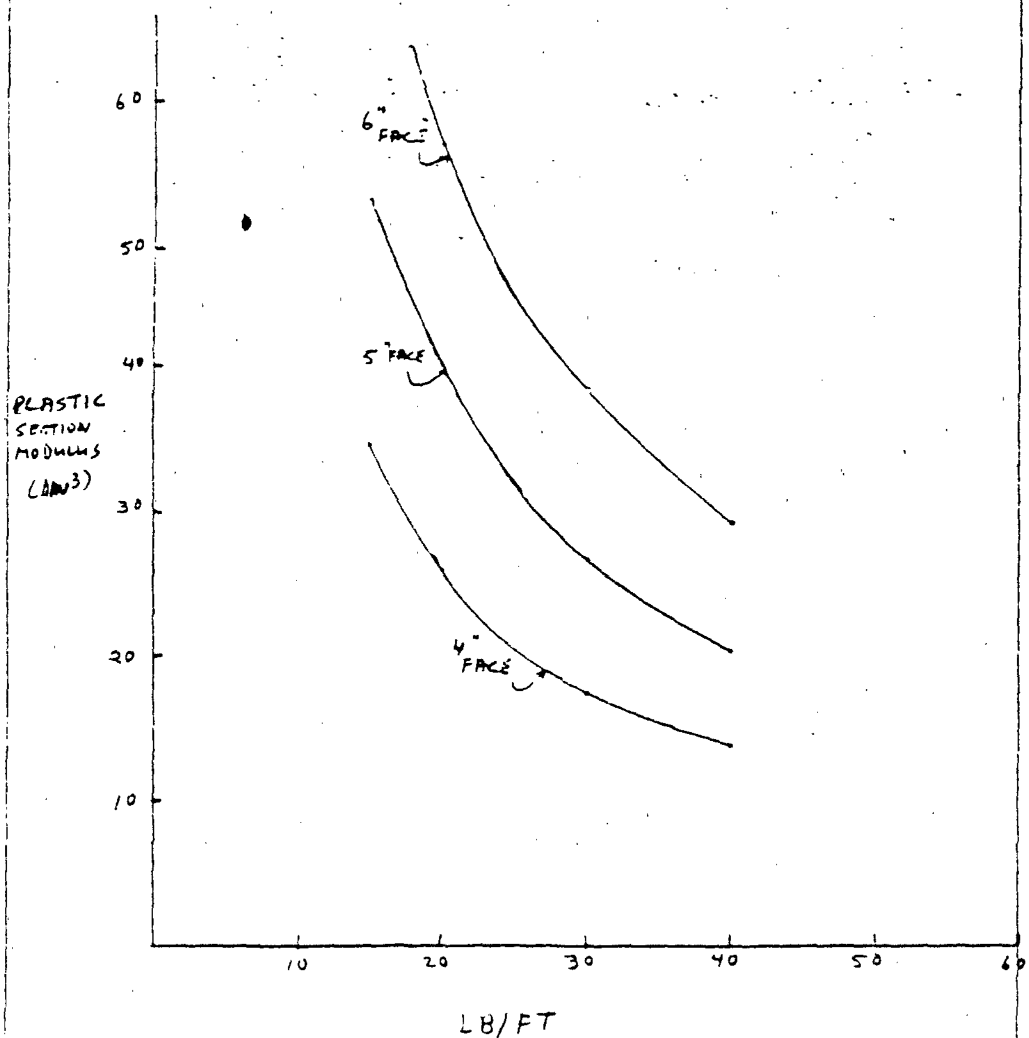
SHEET NO. 5 OF 5

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: DIVIDING WALL DESIGN
BY: B. MORRIS DATE: 23 JUL 19 82 CHECKED BY: ________ DATE CHECKED: ________ 19 ____



STEEL WT IN 15" RC WALL

FLEXURE, EACH FACE #10 @ 8"

$WT = 4.3\ LB/FT \times 5'\ HIGH \times \frac{12}{8} = 32.3 \times 2\ FACES = 64.6\ LB/FT$

SUPPORT SHEAR — #5 @ 8"

$WT = 1.04\ LB/FT \times 4' \times \frac{12}{8} = 6.2\ LB/FT$

LACING #5 $WT = 1.04 \times 4 \times \frac{12}{8} = 6.2$

TOTAL 77 LB/FT

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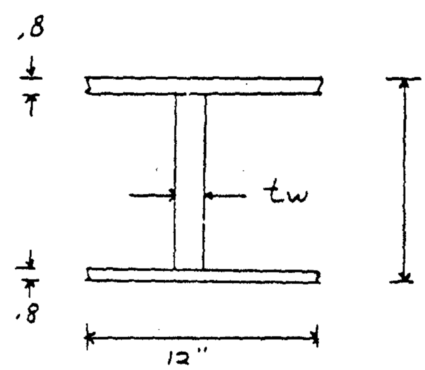
SHEET NO. 1 OF 1

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: STEEL DIVIDING WALLS
BY: E. MORRIS DATE: 4 AUG 1982 CHECKED BY: DATE CHECKED: 19

7.4.3. DESIGN FOR TWO STEEL SECTIONS WITH SAND IN BETWEEN

FROM THE WORK STARTING ON PAGE 7-10, TWO SECTIONS OF STEEL, EACH 0.8 IN THICK, WILL STOP THE DESIGN FRAGMENT.



DETERMINE WEIGHT OF 1 FT OF WALL (JUST THE WEIGHT OF THE 0.8" PLATES)

$$WT = 2(.8)(12) \times 60 \text{ INCH HEIGHT} \times .283 \frac{LB}{IN^3}$$

$$WT = 326 \text{ LB/FT OF DIVIDING WALL}$$

IF THE WEB THICKNESS IS 0.8", THE WEIGHT OF THE ENTIRE PIECE IS 467 LB/FT.

THIS IS TOO MUCH AND A STEEL DIVIDING WALL SEEMS IMPRACTICAL.

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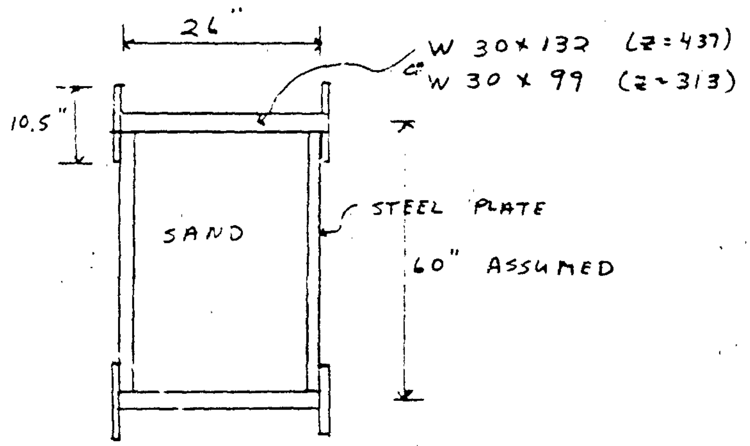
SHEET NO. 1 OF 3

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: SAND - FILLED DIVIDING WALLS
BY: E. MORRIS DATE: 4 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

THE DESIGN FRAGMENT REQUIRES 26"-28" OF SAND TO STOP IT.

ASSUME THE WALL CROSS-SECTION IS AS FOLLOWS:



EACH W30×132 (W30×99) MUST WITHSTAND DESIGN LOADS OVER A 5' LENGTH OF WALL

WT PER VERTICAL FOOT = (5 × $\frac{26}{12}$ × 100) + 132 = 1215 LB/FT
(WIDTH, SAND DEPTH, DENS)

DESIGN PEAK PRESS IS 26,250 PSI, .00014 SEC = T_D.

USE "STEEL" PROGRAM TO DETERMINE REQ'D Z.

FDY = 60,000 L = 60" θ = 12° W = 1215×5 = 6075 lb
CANTILEVER
TOTAL PEAK LOAD = 26,250 × 60 × 60 = 9.45×10^7 LB

REQ'D Z = 93.55 < Z OF W30×99. OK

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SHEET NO. 2 OF 3

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: SAND-FILLED DIVIDING WALLS
BY: B. MORRIS DATE: 4 AUG 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

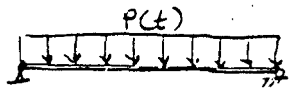
DETERMINE THICKNESS OF STEEL PLATES, TREATING THE 2 PLATES AS A SINGLE ONE.

CONSIDER A SIMPLY SUPPORTED BEAM 60" LONG, 1" WIDE, WITH A WEIGHT OF

$$WT = 1" \times 60" \times 26" \times \frac{100 \text{ \#}/ft^3}{1728 \text{ in}^3/ft^3} = 90 \text{ LBS}$$

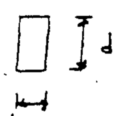
$$MASS = \frac{90}{386.4} = .23 \text{ lb} \frac{sec^2}{in}$$

P(t)



60"

CROSS-SECTION



$b = 1$

$$S = \frac{bd^2}{6} \qquad Z = \frac{bd^2}{4} \qquad I = \frac{bd^3}{12}$$

FOR ELASTIC RESPONSE, $K = \frac{384EI}{5L^3} = \frac{384(30 \times 10^6)\left(\frac{1d^3}{12}\right)}{5(60^3)}$

$$\boxed{K = 889 d^3}$$

FROM BIGG'S, $K_{LM} = .78 \Rightarrow M_e = .78 \frac{90}{386.4} = .182$

NAT'L PERIOD $= T = 2\pi \sqrt{\frac{M_e}{K}} = 6.28 \sqrt{\frac{.182}{889 d^3}}$

$$\boxed{T = .09 d^{-\frac{3}{2}}}$$

$$M_p = FDY * Z = 60,000 \frac{1 \times d^2}{4} = 15,000 d^2$$

MAX RESISTANCE $R_m = \frac{8M_p}{L} = \frac{8 \times 15,000 d^2}{60}$

$$\boxed{R_m = 2000 d^2}$$

PEAK FORCE $= \boxed{F_1 = 26,250 \times 60 = 1.58 \times 10^5}$

ELASTIC DEFL $= \frac{R_m}{K} = \frac{2000 d^2}{889 d^3} = \frac{2.25}{d}$

FOR 12° ROTATION, $\Delta_{max} = 30 \tan 12° = 6.4"$

ROTATION $= \tan^{-1} \frac{\Delta_{max}}{30}$

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COMPUTATION SHEET

PROJECT NO.: 02 - 7092 SPONSOR: CERL
SUBJECT: SAND - FILLED DIVIDING WALLS
BY: B. MORRIS DATE: 4 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 __

We have automated solutions to elastic-plastic, one degree of freedom systems in a program "ONEDF".
USE THIS PROGRAM TO DETERMINE MAX DEFL FOR VARIABLE "d."

FDY = 60,000

d	$I = \frac{d^3}{12}$	$S = \frac{d^2}{6}$	$Z = \frac{d^2}{4}$	Δ_{MAX}	ROTATION
1	.083	.17	.25	1.06	2.02°
.5	.010	.042	.0625	13.7	24.5°
.75	.035	.0938	.141	2.86	5.44°

CONCLUSION: CAN USE TWO 3/8" PLATES SEPARATED BY LESS THAN 26" OF SAND SINCE THE PLATES WILL SERVE TO REDUCE FRAGMENT SPEED.

DETERMINE WEIGHT OF STEEL PER FOOT OF WALL:

$$WT = \tfrac{1}{5}(6)(99) + \underline{.75}(12)(60)(.283) = 153 \text{ LB/FT}$$

1.6" STEEL OR 26" SAND WILL STOP THE FRAGMENT
SO 1" STEEL ≈ 16" SAND.

IF USE TWO 1/2" PLATES, NEED .8" STEEL = 13" SAND ADDITIONAL.

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SHEET NO. 1 OF 3

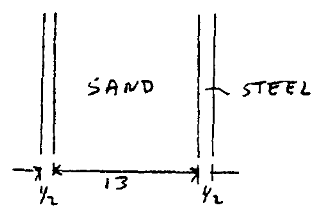
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: REFINEMENT OF SAND DIVIDING WALL
BY: P. MORRIS DATE: 6 AUG 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

FROM PAGE 7-24, TWO 3/8" PLATES WITH 26" OF SAND WILL WORK.

1.6" STEEL OR 26" SAND IS REQUIRED TO STOP FRAGMENT $\Rightarrow$ 1" STEEL $\approx$ 16" SAND

WITH TWO 1/2" PLATES, HAVE 1" STEEL SO NEED .8" STEEL OR 13" SAND.

LOOK AT:



FOR A 1" x 60" STRIP, $WT = 2(\frac{1}{2})(1)(60)(.283) + 1(60)(13)\frac{100}{1728}$

$WT = 62$ LB

FROM PAGE 7-24, $I = .083$ $S = .17$ $Z = .25$ $F_{DY} = 60{,}000$

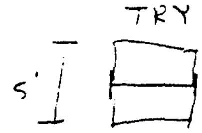
PEAK FORCE $= 1.58 \times 10^5$ $T_D = .00014$ SEC

USE "ONEDF" TO DETERMINE MAX DEFL. OF THIS SECTION:

$\Delta_{max} = 1.44"$
ROTATION $= 2.74°$

NOW SELECT A STEEL SECTION WITH 14" BETWEEN FLANGES:

TRY W18 x 35 $I = 513$ $S = 57.9$ $Z = 66.8$



TOTAL WT = 5' HT x 35 (W18x35) + 60" HT x 62 (SAND + PLATE) = 3895 LB

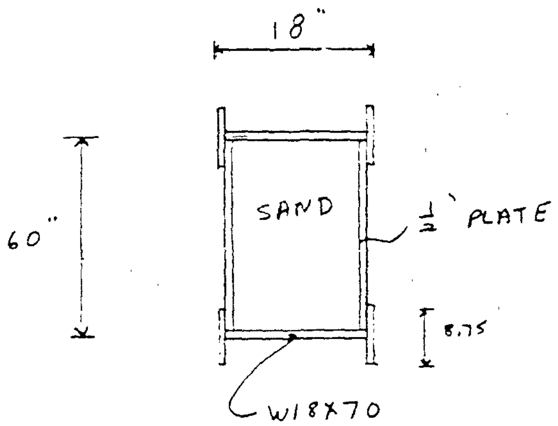
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: REFINEMENT OF SAND DIVIDING WALL
BY: B. MORRIS DATE: 6 AUG 19 82 CHECKED BY: DATE CHECKED: 19

USE "STEEL" PROGRAM TO DETERMINE REQUIRED Z.

$$Z(\text{REQ'D}) = 144.7 > Z(W18 \times 35)$$

TRY W18X70 $Z = 145$ OK SINCE WT WILL INCREASE SLIGHTLY.

FINAL SOLUTION:



STEEL WT PER FT OF WALL: $\frac{70 \times 5 + 1 \times 60 \times 60 \times .283}{5} = 274$ LB

CHECK FLOOR REACTION SHEAR CAPABILITY OF W18X70:

$$M_{cap} = FDY * Z = 60{,}000 \times 145 = 8.7 \times 10^6$$

FLOOR REACTION (PER TM5-1300) $= V_s = \frac{2M}{L} = \frac{2(8.7 \times 10^6)}{60}$

$$V_s = 2.9 \times 10^5 \text{ LB}$$

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: REFINEMENT OF SAND DIVIDING WALL
BY: B. MORRIS DATE: 6 AUG 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

FOR W18X70, WEB THICKNESS = .438"

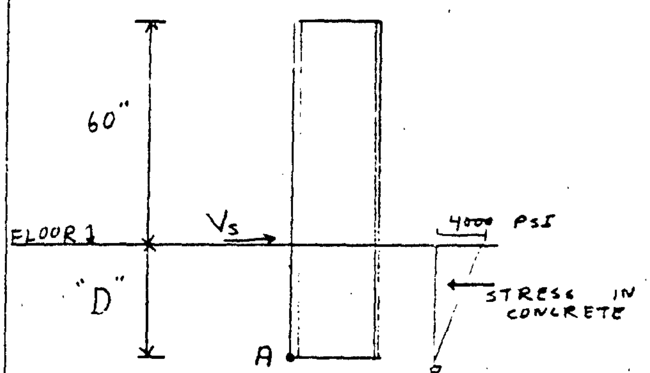
WEB HEIGHT = $18 - 2t_f = 18 - 2(.751) = 16.5"$

WEB AREA = 7.2 IN^2

SHEAR STRESS = $\frac{V_s}{\text{WEB AREA}} = \frac{2.9 \times 10^5 \text{ LB}}{7.2 \text{ IN}^2} = 40300$ PSI

THIS IS LESS THAN FY = 50,000 OK

LOOK AT FLOOR CONNECTION.



ASSUME THAT FLANGES OF THE W18X70 ARE REINFORCED BELOW THE FLOOR SO THE WHOLE FLANGE AREA RESISTS THE FORCE V_s.

ASSUME BEAM ROTATES ABOUT POINT "A".

$$\Sigma M_A = 0 \Rightarrow \quad V_s D = \underbrace{\tfrac{1}{2}(4000)}\underbrace{(8.75)(D)} \times \tfrac{2}{3} D$$

Force x Dist = Avg STRESS x AREA x DIST

$$2.9 \times 10^5 = 11,667 D$$

$$\boxed{D = 24.9"}$$

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COMPUTATION SHEET

SHEET NO. 1 OF 1

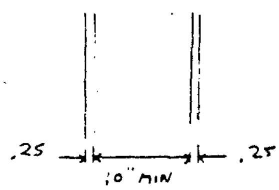
PROJECT NO. 02-7092 SPONSOR: CERL
SUBJECT: STEEL - CONCRETE COMPOSITE DIVIDING WALL
BY: E. MORRIS DATE: 1 SEP 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

7.4.4 STEEL/CONCRETE COMPOSITE WALL

$P_{max} = 26,250$ PSI $T_D = .0004$ SEC

1.6" STEEL OR 1.6×9 = 14.4" CONCRETE WILL STOP THE FRAGMENT

USE THE FOLLOWING SECTION:



WITH 2×.25 = .5" PLATE, NEED ADDITIONAL 1.1" STEEL = 9.9" CONCRETE, HENCE 10" MINIMUM

FROM PAGE 7-16, "DIVIDING WALL DESIGN,"

A 12" CONCRETE WALL WITH $A_s = .282$ IN²/IN WITH

A MOMENT ARM OF 12-6=6" WILL SUFFICE.

USE "ONEDF2" TO CHECK MAX DEFLECTION

FDY = 90,000 Fc' = 4000 $A_s = .25$ IN²/IN

DC = 10.25" TOTAL THICK = 10 + .5 × $\frac{489}{150}$ ≈ 12

$\Delta_{MAX} = 8.38"$ ROTATION = 7.95° OK

APPENDIX 8

WEAPON LOADOUT

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SHEET NO. 1 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: REQUIREMENTS
BY: [illegible] DATE: 6-23 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

Weapon Movement and Handling (M/H)
Requirements and Constraints

1. M/H system must be compatible with bay sealing requirements
2. Must be able to move weapons without building power
3. M/H equipment must be on current NRC-approved list
4. Cannot "do" anything to round except move it (i.e. min hazard)
5. Workflow (a) storage to dock to truck
   (b) truck to dock to storage
   (c) storage to maintenance to storage
6. Must provide 4,000 pound overhead crane in maintenance area
7. Must have ≤ 5000 lb dead load on dock at any one time
8. Loadout cannot compromise chemical collective protection system.
9. Loadout 57 weapons of specified mix in ≤ 2 hours.
10. External weapon transport by $2\frac{1}{2}$ and 5 ton standard trucks only
11. Crew of two per truck
12. Weapons are processed in/out of facility by serial number
13. M/H compatible with 12 foot clear ceiling height
14. Weapons transported beyond facility as a group.
15. Load dock ≤ 500 ft^2
16. M/H must minimize manpower requirements
17. M/H must minimize cost (investment and O&S)
18. M/H system must be able to operate in a debris environment following an explosion in a bay.

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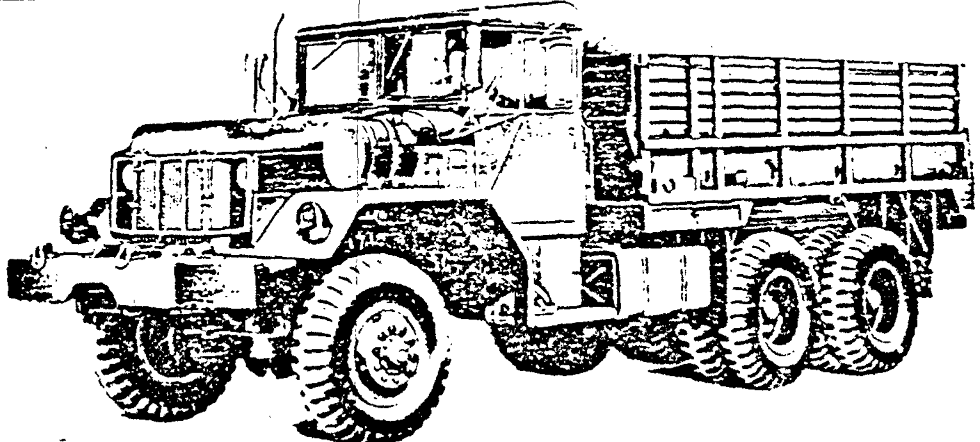
COMPUTATION SHEET

SHEET NO. 2 OF 3!

PROJECT NO.: 02-7692 SPONSOR: CERL
SUBJECT: 5-TON VEHICLES
BY: [illegible] DATE: 6-23 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

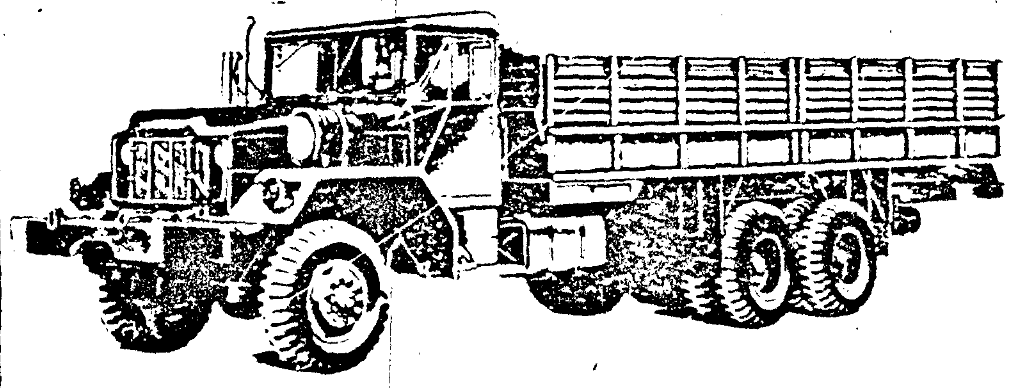


SHIPPING DIMENSIONS

OVERALL LENGTH	317 in.	SHIPPING CUBAGE	1538 cu. ft.
OVERALL HEIGHT	85-1/2 in.	SHIPPING WEIGHT	21686 lbs.
OVERALL WIDTH	96 in.	SHIPPING TONNAGE	10.84 tons

AT 28862

TRUCK, CARGO, M813, w/w - left front view



SHIPPING DIMENSIONS

OVERALL LENGTH	392-13/16 in.	SHIPPING CUBAGE	1878 cu. ft
OVERALL HEIGHT	85-1/2 in.	SHIPPING WEIGHT	25724 lbs.
OVERALL WIDTH	96in.	SHIPPING TONNAGE	12.86 tons

AT 28038

TRUCK, CARGO, M814, w/w - left front view

5-TON VEHICLES

1-5. Tabulated Data

a. *General.*

Crew 2

Vehicle weight (empty) with front winch (except as noted).

M813 .... 21,686 lbs.
M813A1 .... 21,686 lbs.
M814 .... 25,724 lbs.
M815 .... 21,790 lbs.
M816 .... 36,000 lbs.
M817 .... 24,323 lbs.
M818 .... 19,260 lbs.
M819 .... 34,480 lbs.
M820 .... 27,340 lbs. wo/w
M820A1 .... 27,550 lbs. wo/w
M820A2 .... 29,030 lbs. wo/w
M821 .... 28,710 lbs.

NOTE

Deduct 714 pounds for vehicles not equipped with a front winch.

Payload (on highway):

M813, M813A1, M814, M815, and M821 .... 20,000 lbs. 10T
M816 (on crane) .... See crane safe load plate
M817 .... 20,000 lbs. cargo
M818 .... 25,000 lbs. weight on fifth wheel
M819 .... 16,000 lbs. weight on fifth wheel
M820, M820A1 and M820A2 .... 15,000 lbs.

Payload (off highway):

M813, M813A1, M814, M815, M817, and M821 .... 10,000 lbs. cargo 5T
M816 (on crane) .... See crane safe load plate
M818 .... 15,000 lbs. weight on fifth wheel
M819 .... 12,000 lbs. weight on fifth wheel
M820, M820A1, and M820A2 .... 5,000 lbs.

NOTE

Payload limits shown are without personnel (400 lb) 15,000 and 12,000-pound loads on fifth wheel are for limited cross country operation.

b. *Dimensions.*

Height overall:

M813, M813A1, and M814 .... 86 1/2 in.
M815 .... 118 in.
M816 .... 106 in.
M817 .... 110 5/8 in.
M818 .... 89 in.
M819 .... 132 in.
M820, M820A1, and M820A2 ...... 136.37 in.
M821 .... 120 3/4 in.

Length, overall, w/o front winch:

M813, M813A1, and M815 .... 304 in.
M814 .... 377 5/16 in.
M817 .... 273 in.
M818 .... 264 3/8 in.
M820, M820A1, and M820A2 ...... 360 in.

Length, overall, w/front winch:

M813, M813A1, and M815 .... 317 in.
M814 .... 392 13/16 in.
M816 .... 356 in.
M817 .... 288 1/2 in.
M818 .... 280 in.
M819 .... 369 1/4 in.
M821 .... 372 1/2 in.

Width:

M813, M813A1, and M815 .... 96 5/8 in.
M814, M816, and M818 .... 97 in.
M817 .... 97 1/4 in.
M819 .... 97 11/16 in.
M820, M820A1, and M820A2 ..... 98 in.
M821 .... 115 in.

Ground clearance, minimum

M813, M813A1, M814, M815, M817, and M819 .... 10 1/2 in.
M816, and M819 .... 11 in.
M820, M820A1, M820A2, and M821 .... 13 in.

Turning circle (dia), w/o front winch:

M813, and M813A1 .... 83 ft. 8 in.
M814, M820, and M820A1 .... 93 ft. 10 in.
M817 .... 78 ft. 10 in.
M818 .... 76 ft. 8 in.
M820A2 .... 94 ft. 10 in.

Turning circle (dia) w front winch:

M813, M813A1, and M815 .... 84 ft. 8 in.
M814 .... 95 ft. 4 in.
M816, and M819 .... 94 ft. 10 in.
M817 .... 80 ft. 2 in.
M818 .... 78 ft. 6 in.
M21 .... 95 ft. 7 in.

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COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: 5-TON VEHICLES
BY: [illegible] DATE: 6-23 1983 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

c. Capacities.

Cooling system .... 42 qts.
Crankcase: (wet refill) .... 23 qts.
Oil filter .... 2 qts.
Differentials, each .... 12 qts.
Transmission w/o power takeoff .. 13 pts.
w/ power takeoff ... 14 pts.
Transfer w/o power takeoff ...... 5 qts.
w/ power takeoff ...... 5 1/2 qts.

Winch:

Front .... 2.6 qts.
Rear .... 3.0 qts.
Midship .... 2.6 qts.

Fuel tank:

M813, M813A1, M814, M815, M819, M820, M820A1, M820A2, and M821 .... 78 gals.
M816 .... 133 gals.
M817, and M818 .... 110 gals.

d. Performance.

Maximum speed .... 59 mph @ 2100 rpm.

Fording depth:

With fording kit installed .... 78 in.
Without fording kit .... 30 in.
Midship winch capacity (max) .... 20,000 lbs.
Front winch capacity (max) ...... 20,000 lbs.

Maximum towed load (on highway):

All models except M818, and M819 .... 30,000 lbs (pintle)
M818 .... 55,000 lbs. (fifth wheel)
M819 .... 46,000 lbs. (fifth wheel)

Maximum towed load (off highway):

All models except M818, and M819 .... 15,000 lbs. (pintle)
M818 .... 20,000 lbs. (fifth wheel)
M819 .... 30,000 lbs. (fifth wheel)

e. Tire Pressures.

Highway (psi.):

M813, M813A1, M814, M816, M817, and M818 70
M815 80
M819 75
M820, M820A1, and M820A2 90
M821 55

Cross country (psi):

All models 35

Mud, sand, and snow (psi):

All models 15

f. Electrical System.

Batteries (four connected in series-parallel)

Model 6TN23
Voltage (each) 12
Ground .... negative

g. Cooling System.

Surge tank filler cap:

Opening pressure .... 7 psi

Thermostat:

Starts to open at .... 160°F.
Fully open .... 185°F.

h. Brakes.

Service brakes:

Type .... Air-hydraulic
Brake pedal free travel .... 1/4 to 1/2 in.

Hand brakes:

Location .... transfer rear output shaft

i. Front Winch.

Capacity .... 20,000 lbs.

Cable length:

All models except M816, and M819 .... 200 ft.
M816, and M819 .... 280 ft.

j. Rear Winch (M816).

Capacity .... 45,000 lbs.
Cable length .... 280 ft.

k. Midship Winch (M815).

Capacity .... 20,000 lbs.
Cable length .... 200 ft.

TM 9-2320-260-10
April 1970

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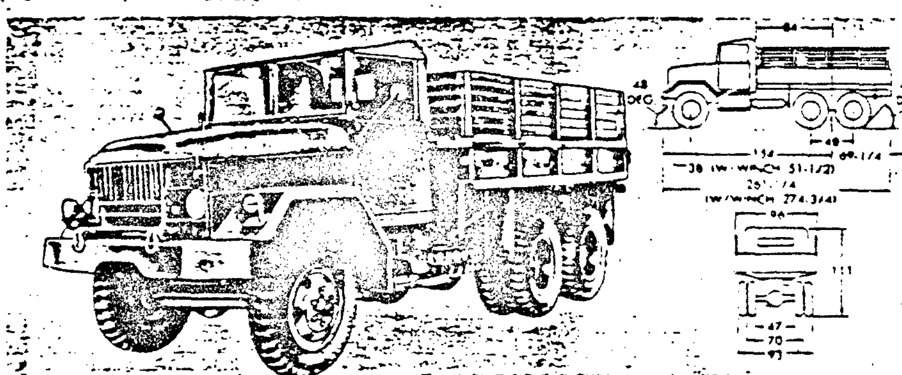
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7692 SPONSOR: CERL
SUBJECT: 2½-TON VEHICLES
BY: [signature] DATE: 6-22 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

Ref TM 9-500

TRUCK, CARGO: 2½-TON, 6x6, M35 AND M35A1, W/ AND W/O WINCH, W/E



ORD E4017

Major Items

Model	Line item No.	Federal stock No.
M35, w/wn, soft top	4-40141-30	2320-835-4444
M35, w/o, soft top	4-40110-28	2320-835-4443
M35, w/wn, hard top	4-40141-31	2320-835-8520
M35A1, w/o wn, hard top	4-40110-27	2320-835-8519
M35A1, w/wn	4-40141-32	2320-542-5634
M35A1, w/o wn	4-40110-29	2320-542-5633

General

TRUCK, CARGO: 2½-ton, 6 x 6, M35 and M35A1, is a vehicle used to transport general cargo or personnel. The truck has troop seats for 14 passengers whom it can carry in lieu of cargo. It is dual-tired on the rear wheels. The body is a 12-foot steel flat-bed type. Sides and tarpaulin frames are removable.

Differences among models

The M35 cargo truck has a spark plug ignition engine. The M35A1 has a multifuel, compression ignition engine.

Data plate location

Classification: M35—Standard A (OTCM 36481).
M35A1—Standard A (OTCM 37871).

CHARACTERISTICS

Crew 2
Passengers 14
Length, overall:
- W/winch .... 278 in.
- W/o winch .... 262 in.

Width overall .... 96 in.
Height (as supplied to travel) .... 112 in.
Weight, net:
- M35
  - W/o Winch .... 12,444 lb
  - W/ Winch .... 12,880 lb
- M35A1
  - W/o Winch .... 13,443 lb
  - W/Winch .... 13,840 lb

Payload:
- Highway:
  - M35 .... 10,340 lb
  - M35A1 .... 10,000 lb
- Cross-country:
  - M35 .... 5,350 lb
  - M35A1 .... 5,350 lb

Rear axle gear ratio:
- M35 .... 6.72:1
- M35A1 .... 6.72:1

Axle load:
- Empty:
  - Front:
    - M35 .... 3,810 lb
    - M35A1 ....
  - Rear:
    - M35 .... 3,335 lb
    - M35A1 ....
- Loaded:
  - Front:
    - M35 .... 6,700 lb
    - M35A1 ....
  - Rear:
    - M35 .... 8,340 lb
    - M35A1 ....

Tires:
- Ply 10
- Size .... 9.00 x 20
- Pressure:
  - Highway
    - Front .... 70 psi
    - Rear .... 45 psi
  - Cross-country
    - Rear .... 35 psi
    - Front .... 45 psi
  - Sand .... 15 psi
- Tread, center-to-center front .... 67⅝ in.

Electrical system:
- Number of batteries (12 volts each) 2
- Voltage 24
- Ground .... Negative

Fuel octane rating (gasoline) 80
Fuel cetane rating:
- Compression-ignition engine type 33-37
- Diesel 40

Capacities:
- Cooling systems:
  - M35 (w/o heater) .... 22 qt
  - M35A1 .... 34 qt

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COMPUTATION SHEET

SHEET NO. 6 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: 2½-TON VEHICLES
BY: [signature] DATE: 6-22 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

Crankcase refill:
- M35 .... 9 qt
- M35A1 .... 18 qt

Steering gear .... 1 pt
- Fuel tank .... 50 gal
- Axle, each .... 7 qt

Transmission:
- W/power take-off .... 10¼ pt
- W/o power take-off .... 8½ pt

Transfer .... 7 qt
Winch clutch housing .... 1 qt
Winch worm housing .... 1¼ pt

Brakes.
- Manufacturer .... Bendix-Westinghouse
- Type .... Air-hydraulic
- Parking, type .... Transfer

Engine:
- M35 truck:
  - Manufacturer:
    - Reo Motors Inc .... Model OA-331
    - Continental .... Model COA-331
  - Type .... gasoline, valve-in-head 4-cycle
  - Number of cylinders .... (in line) 6
  - Displacement .... 331 cu in.
  - Bore .... 4⅛ in.
  - Stroke .... 4⅛ in.
  - Compression ratio 6.75:1
  - Governed speed .... 3,600 rpm
  - Brake horsepower (w/std accessories) .... 146 @ 3,400 rpm
  - Torque (w/std accessories) .... 248 lb-ft @ 1,400 rpm
- M35A1 truck:
  - Manufacturer .... Continental Model LDS-427-2
  - Type .... multifuel, compression-ignition
  - Number of cylinders .... (in line) 6
  - Displacement .... 427 cu in.
  - Bore .... 4.3125 in.
  - Stroke .... 4.875 in.
  - Compression ratio 20:1
  - Governed speed .... 2,800 rpm
  - Brake horsepower (w/std accessories .... 140 @ 2,600 rpm
  - Torque (w/std accessories) .... 340 lb-ft @ 1,400 rpm

Transmission:
- Manufacturer:
  - M35 .... Spicer Mfg Co., Model 3052
  - M35A1 .... Spicer Mfg Co., Model 3053A
- Type .... synchromesh
- Speeds:
  - Forward 5
  - Reverse 1
- Gear ratio:
  - High:
    - M35 .... 1:1
    - M35A1 .... 0.79:1
  - Low:
    - M35 .... 7.58:1
    - M35A1 .... 5.02:1
  - Reverse:
    - M35 .... 7.36:1
    - M35A1 .... 4.90:1

Transfer:
- Manufacturer:
  - M35 .... Wisconsin Axle Div., Model T-136-10
  - M35A1 .... Rockwell-Standard, Model T-136-21
- Speeds 2
- Gear ratio:
  - High:
    - M35 .... 1:1
    - M35A1 .... 1:1
  - Low:
    - M35 .... 1.98:1
    - M35A1 .... 1.89:1

Live axle, type .... double-reduction, full-floating
Body cargo space .... 456 cu ft
Winch capacity .... 10,000 lb
Chassis M45

Ground clearance .... 12.5 in.

Angle of approach:
- W/wn .... 38 deg
- W/o wn .... 46 deg

Angle of departure .... 44 deg

PERFORMANCE

Computed grade ability in lowest gear:
- M35 .... 64 percent
- M35A1 .... 60 percent

Turning radius:
- W/wn .... 35½ ft
- W/o wn .... 36½ ft

Fuel consumption:
- M35 .... 6 mpg
- M35A1 .... 9.3 mpg (gasoline); 9.7 mpg (CIE fuel); 11.3 mpg (diesel)

Cruising range:
- M35 .... 350 miles
- M35A1 .... 500 miles

Allowable speed (governed):
- M35 .... 60 mph
- M35A1 .... 58 mph

Fording depth.
- W/fording kit .... 72 in.
- W/o fording kit .... 30 in.

Towed load:
- Highway .... 10,000 lb
- Cross-country .... 6,000 lb

EQUIPMENT

Basic Issue Items:
- M35—See TM 9-8022, C3
- M35A1—See TM 9-2320-235-10

INSTRUCTIONAL MATERIAL STORAGE AND SHIPMENT DATA

Within Continental United States

Shipped 1 truck, uncrated — W/Winch — W/o Winch

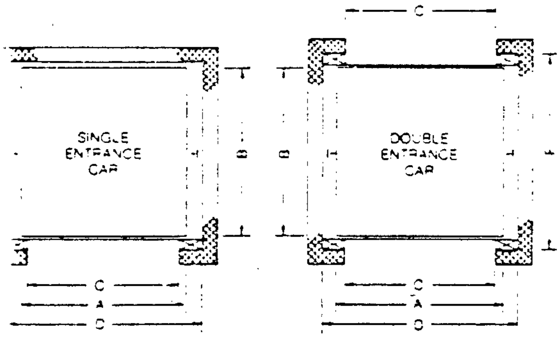
- M35:
  - Length .... 276 in.
  - Width .... 96 in.
  - Height .... 112 in.
  - Volume .... 1,718 cu ft
  - Gross weight .... 24,064 lb
  - Ship tons 42.97
  - Area .... 259 sq ft
- M35A1:
  - Length ....
  - Width ....
  - Height ....
  - Volume ....
  - Gross weight ....
  - Ship tons ....

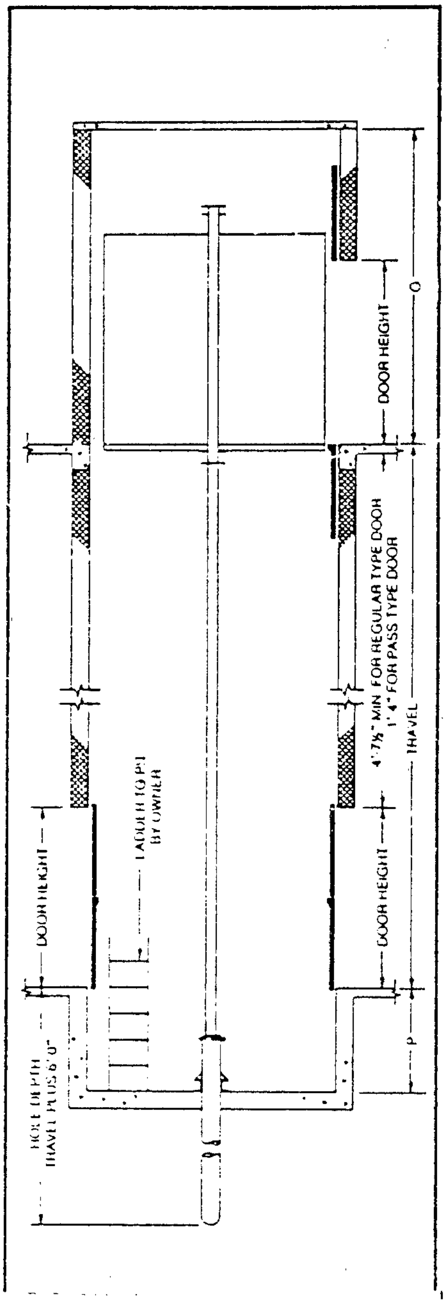
Outside Continental United States

Shipped 1 truck, uncrated — W/Winch — W/o Winch

- M35.
  - Height ....
  - Volume ....
  - Gross weight ....
  - Ship tons ....
  - Area ....
- M35A1:
  - Length ....
  - Width ....
  - Height ....
  - Volume ....
  - Gross weight ....
  - Ship tons ....

References: M35—SNL G-742, TM 9-2300-223-20P, TM 9-2320-209-35P, TM 9-2320-209-10P, TM 9-8022, TM 9-1828A, TM 9-8601, TM 9-8615, TM 9-8623, TM 9-8647, TM 9-2920-210-34, LO 9-2320-209-12.
M35A1—TM 9-2320-235-10, TM 9-2320-235-20, TM 9-2320-235-20P, TM 9-2320-235-35, TM 9-2320-235-35P, TM 9-2300-223-20P, LO 9-2320-235-10.





RECOMMENDED SIZES AND CAPACITIES				
	CAPACITIY IN POUNDS			
DIMENSIONS	2500	4000 5000 6000	8000	10,000
A	5'-4"	8'-4"	8'-4"	8'-4"
B	7'-0"	10'-0"	12'-0"	14'-0"
C	5'-0"	8'-0"	8'-0"	8'-0"
D*	7'-2"	10'-2"	10'-2"	10'-2"
E**	7'-8"	10'-8"	12'-3"	14'-8"
F***	7'-11"	10'-11"	12'-11"	14'-11"

DIMENSIONS SHOWN ARE FOR POWER OPERATED DOORS OF THE REGULAR TYPE WITH 8'-0" CLEAR OPENING HEIGHT CHANGES REQUIRED IF OTHER THAN ABOVE

*SUBTRACT 5" IF MANUAL DOORS ARE USED
**ADD 1¾" IF PASS TYPE DOORS ARE USED
***ADD 3½" IF PASS TYPE DOORS ARE USED

MINIMUM PIT AND OVERHEAD DIMENSIONS						
	SPEED (FEET PER MINUTE)					
DIMENSIONS	25	50	75	100	150	200
P	4'-6"	4'-6"	4'-6"	4'-6"	4'-6"	4'-6"
O****	15'-0"	15'-0"	15'-0"	15'-0"	15'-2"	16'-0"

DIMENSIONS SHOWN ARE FOR POWER OPERATED DOORS OF THE REGULAR TYPE WITH 8'-0" CLEAR OPENING HEIGHT CHANGES REQUIRED IF OTHER THAN ABOVE

****SUBTRACT 1'-0" IF 7'-0" CLEAR OPENING HEIGHT DOORS ARE USED

POWER UNIT (MACHINE) LOCATION: The most desirable machine room location is on the lowest floor adjacent to the elevator shaft. It may, however, be located remote from shaft if necessary. Typical size for one-car installation 9'-8" x 7'-2" x 8'-0" high. Larger area is required when two or more power units used or for two elevators with common machine room, etc. Enclosure to meet local code requirements must be provided. A sound-isolated machine room is recommended for quietest operation. Adequate heating and ventilation of machine spaces must be provided.

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COMPUTATION SHEET

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT TRUCK REQUIREMENTS
BY: mwf DATE: 6-23 1982 CHECKED BY: ______ DATE CHECKED ______ 19__

5-TON CARGO TRUCKS (6×6)

Model	Front Winch	Drop Side	Overall Length (in)	Overall Width (in)	Payload on hiway	Payload off hiway	Front Winch Capacity	Bed
M813	✓	–	317	95.6	10T	5T	10T	~ 13.3' x 8' 128 ft²
M813A1	✓	✓	317	95.6	10T	5T	10T	~ 13.3' x 8' 128 ft²
M814	✓	–	393	97.0	10T	5T	10T	~ 17' x 8' 168 ft²

2½-TON CARGO TRUCK (6×6)

Model	Front Winch	Drop Side	Overall Length (in)	Overall Width (in)	Payload on hiway	Payload off hiway	Front Winch Capacity	Bed
M35A1	✓	–	276	96.0	5T	2½T	5T	~ 12' x 8'

Longest wpn.
14' x 4.5' x 4.5

Wpn Type 4 15 - 5 ton tks 1(...)

1 - 5 ton w/ stack 12 + 3
2 2 - 2½ ton (8 ...)

6 - 5 ton
3 6 - 2½ ton 2(...)

1 - 5 ton tks
1 1 - 2½ w/ stack (12 bottom, 3 top)

23 - big 5-ton
16 - reg 5-ton
7 - 2½ ton

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 7 OF 31

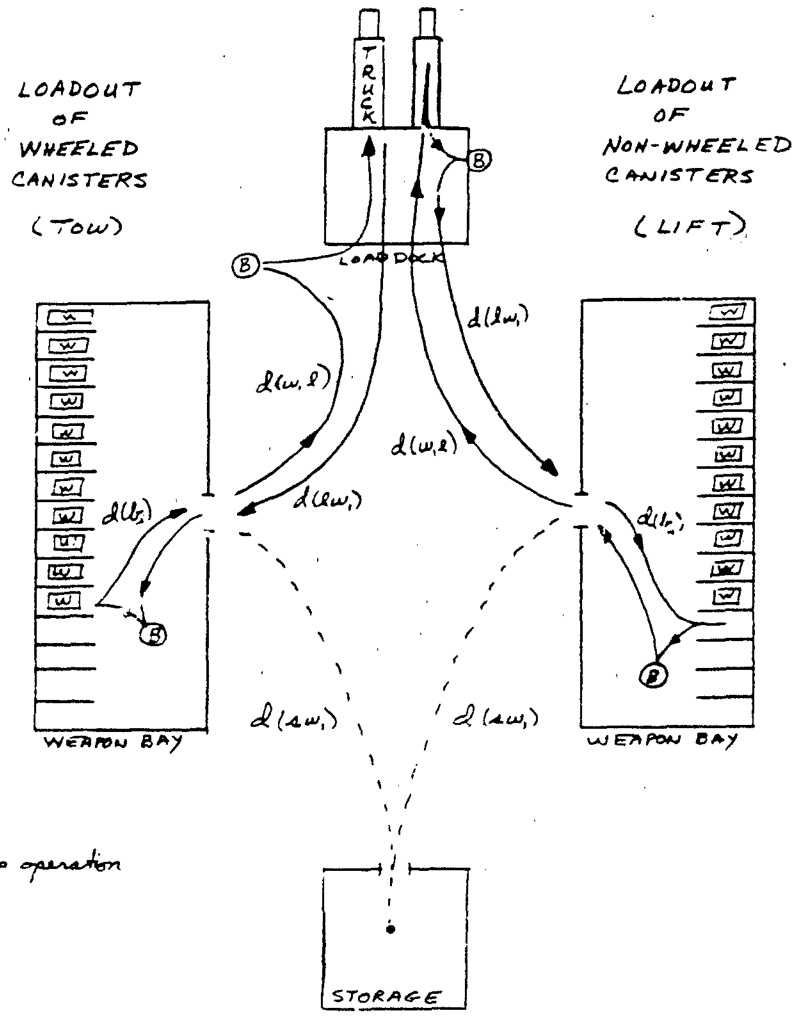
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EQUIPMENT REQUIREMENTS
BY: [illegible] DATE: 9-8 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

For loadout: 4 forklifts
2 trucks at each dock.
11 people: 4 Forklift drivers
1 person in each of 4 bays.
2 checkout people
1 overseers
- 2 spare forklifts
2 20ft roller tracks
~~1~~ 180° rotating pad (15' diameter)

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 10 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LOADOUT
BY: [illegible] DATE: 7-12 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___



Ⓑ Backup operation

Tow wheeled canister to dock; back it onto the truck

Forklift the canister to the dock; drive onto the truck and set in place

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 11 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: TIMELINE FOR LOADOUT
BY: [illegible] DATE: 7-12 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

ABOVE GROUND FACILITY USING FORKLIFTS

Time (sec)	Event
300	Loadmaster instructions (in control room)
120	Mount and start forklifts (in storage area)
(120)	Open blast doors on weapons bay
*	Drive from storage to weapons bay - d(sw)
*	Drive from bay door to first cubicle - d(b)
20	Position forklift with tines under canister
75	Tie forklift to canister; raise canister; backup
*	Drive from first cubicle to bay door - d(b)
*	Drive from weapons bay to loading dock - d(wl)
30	Logout weapon
120	Drive weapon onto truck; position it; set it down; backup
*	Drive from loading dock to weapons bay - d(wl)
*	Drive from bay door to second cubicle - d(b)
20	Position forklift with tines under canister
75	Tie forklift to canister; raise canister; backup
*	Drive from second cubicle to bay door - d(b)
*	Drive from weapons bay to loading dock - d(wl)
30	Logout weapon
120	Drive weapon onto truck; position it; set it down; backup
⋮	Repeat series of steps for cubicles 3 through 15

* Time computed based on distance travelled and assumed forklift rate of travel.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 12 OF 31

PROJECT NO.: 02 - 7092 SPONSOR: CERL
SUBJECT: TIMELINE FOR LOADOUT
BY: [illegible] DATE: 7-12 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

UNDERGROUND FACILITY USING FORKLIFTS

Time (sec)	Event
300	Loadmaster instructions (in control room)
120	Mount and start forklifts (in storage area)
(120)	Open blast doors on weapons bay
*	Drive from storage to weapons bay - d(sw)
*	Drive from bay door to first cubicle - d(b_1)
20	Position forklift with tines under canister
75	Tie canister to forklift; raise canister; backup
*	Drive from first cubicle to bay door - d(b_1)
*	Drive from weapons bay to platform lift - d(wl)
30	Layout weapon
30	Drive onto lift
30	Ride lift to surface (30 ft @ 1 fps)
120	Drive weapon onto truck; position it; set it down; backup
15	Drive onto platform lift
30	Ride lift to bottom (30 ft @ 1 fps)
*	Drive from lift to weapons bay - d(wl)
*	Drive from bay door to second cubicle - d(b_2)
20	Position forklift with tines under canister
75	Tie canister to forklift; raise canister; backup
*	Drive from second cubicle to bay door - d(b_2)
*	Drive from weapons bay to platform lift - d(wl)
30	Layout weapon
30	Drive onto lift
30	Ride lift to surface (30 ft @ 1 fps)
120	Drive weapon onto truck; position it; set it down; backup
⋮	Repeat series of steps for cubicles 3 through 15.

* Time computed based on distance traveled and assumed forklift rate of travel.

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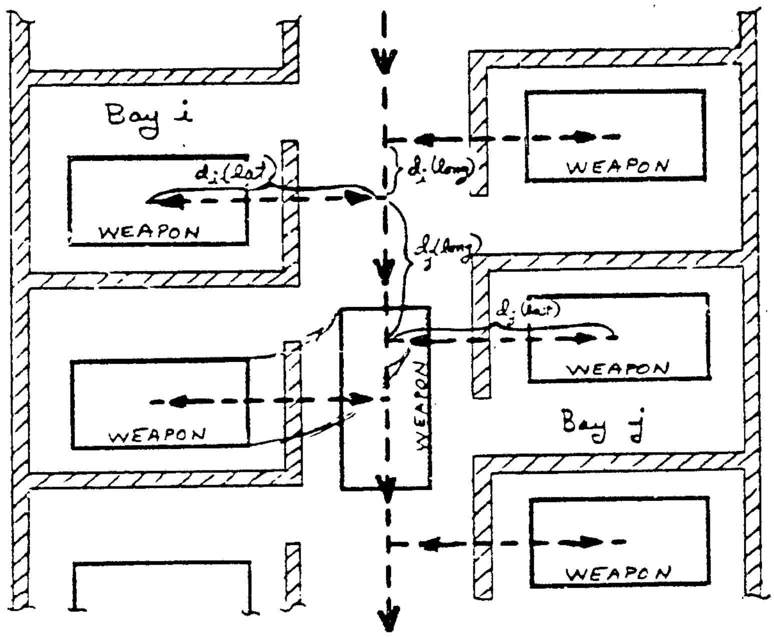
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. 13 of 31

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT CRANE USAGE FOR LOADOUT
BY mwb DATE 7-14 1982 CHECKED BY: ________ DATE CHECKED ______ 19 __



*	d_i (long) rate 1.5 fps
*	d_i (lat) rate 1.5 fps
30 sec	Fine-tune positioning and hookup weapon
25 sec	Lift weapon to 6 ft height (rate 0.25 fps)
*	d_i (lat)
30 sec	Position weapon longitudinally and lower to floor
15 sec	Unhook weapon
—	Forklift moves weapon from this point

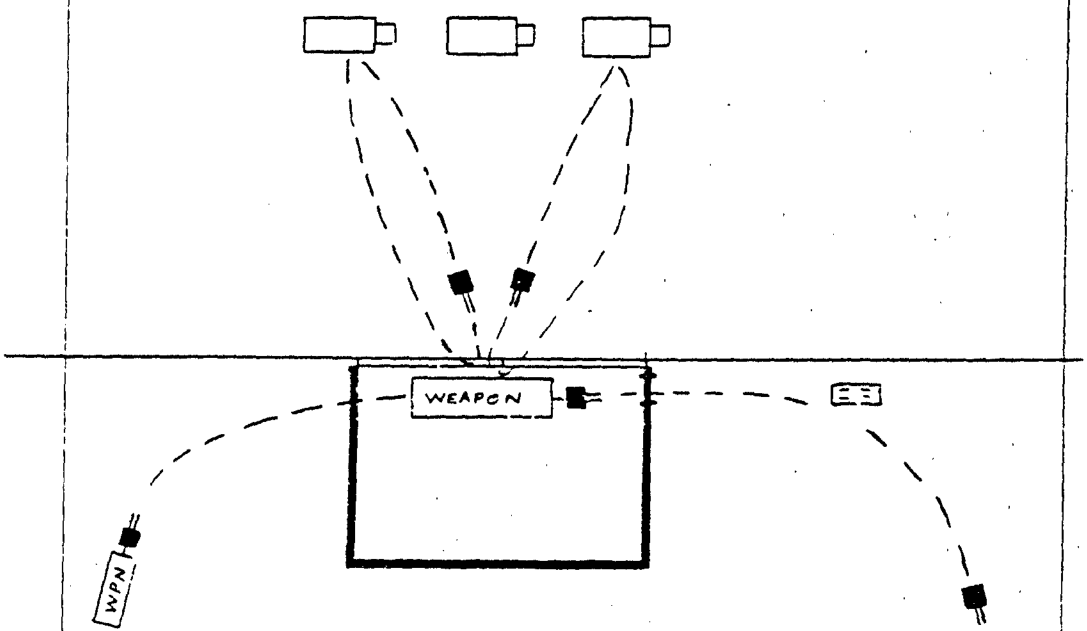
*Time computed based on distance travelled and on assumed crane-travel rates.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO 14 OF 31

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT LOADOUT ON DOLLIES
BY [signature] DATE 7-8-1982 CHECKED BY ______ DATE CHECKED: ______ 19__

LOADOUT OF WEAPONS ON DOLLIES



Must be able to receive/ship weapons following accident
(1) at loading dock
(2) at maintenance bay

Dropside trucks

2 Load decks

Forklifts & Dollies

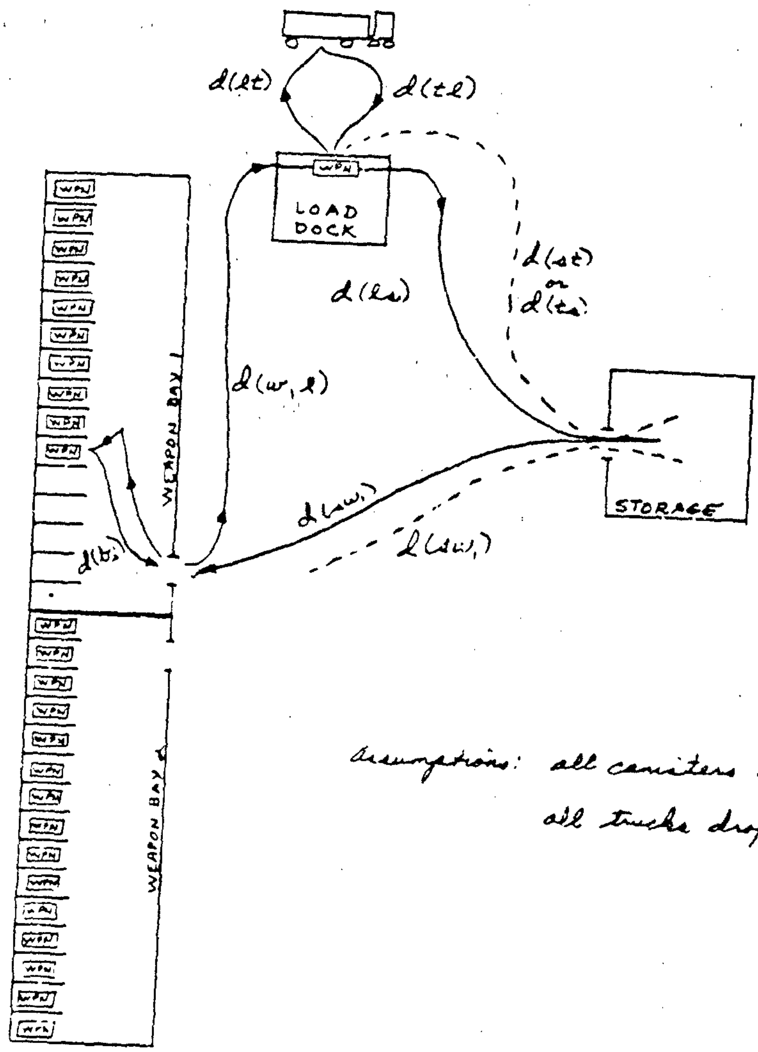
Store on Dollies

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 15 OF 31

PROJECT NO.: 02-7092
SUBJECT: LOADOUT ON DOLLIES SPONSOR: CERL
BY: mwb DATE: 7-8 19 82 CHECKED BY: _____ DATE CHECKED: _____ 19 _____

LOADOUT SCENARIO. — WEAPONS ON DOLLIES



assumptions: all canisters on dollies
all trucks dropside

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 16 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: LOADOUT ON DOLLIES
BY: mwb DATE: 7-12 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 __

LOADOUT TIMELINE — WEAPONS ON DOLLIES

seconds

300 Loadmaster instructions (in control room)
120 Mount and start forklifts (in storage area)
(120) Open blast doors on weapons bay
d(sw,)
d(b,)
10 position forklift for towing
30 dismount; hookup weapon; mount
d(b,)
d(w,l)
30 logout weapon
120 back weapon onto truck
20 dismount; unhook weapon; mount
d(lw,)
d(b,)
10 position forklift for towing
* 30 dismount; hookup weapon; mount
d(b,)
d(w,l)
30 logout weapon
120 back weapon onto truck
20 dismount; unhook weapon; mount
: complete all 15 bays in W1
d(lw,)
d(b,)
20 position forklift with tines under canister.
75 tie canister to forklift; pick up canister; backup.
d(b,)
d(w, l)
30 logout weapon
60 drive weapon onto truck; position it; set it down; backup
: complete all 15 bays in W_2

W_3 and W_4 are emptied at the same time as the above, using the second loading dock.

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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: C2-7092 SPONSOR: CERL
SUBJECT: LOADOUT TIMELINE CALCULATIONS
BY: mwb DATE: 9-8 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

LOADOUT CALCULATIONS

EXAMPLE 1	RECTANGULAR FACILITY	LONG BAYS (DOORS IN MIDDLE)
EXAMPLE 2	SQUARE FACILITY	LONG BAYS (DOORS ON ENDS)
EXAMPLE 3	"L"-SHAPED FACILITY	LONG BAYS
EXAMPLE 4	SEMICIRCULAR FACILITY	LONG BAYS
EXAMPLE 5	SQUARE FACILITY	PIT BAYS
EXAMPLE 6	UNDERGROUND FACILITY (LIFTS)	LONG BAYS

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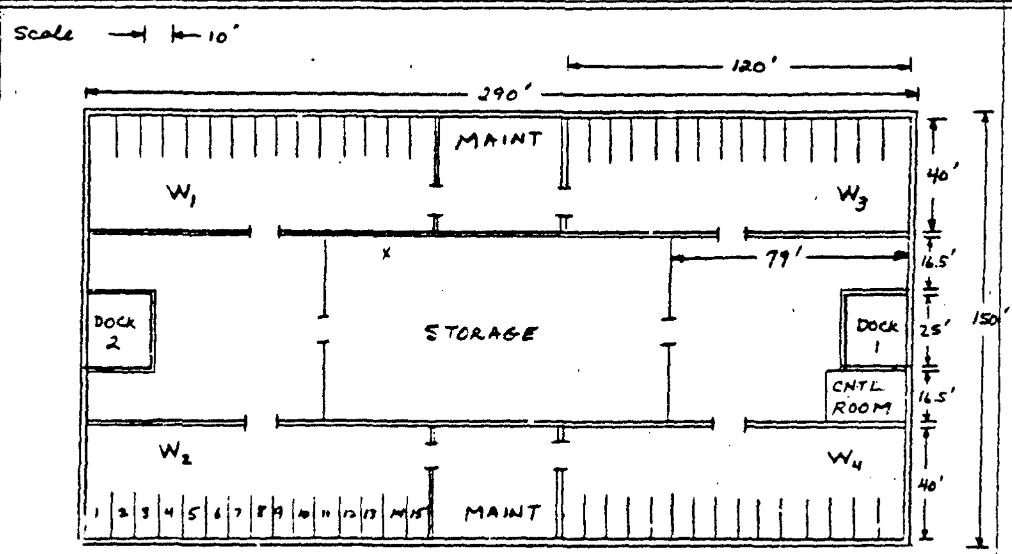
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE LOADOUT 1
BY: mwl DATE: 7-13-1982 CHECKED BY: ______ DATE CHECKED: ______ 19__



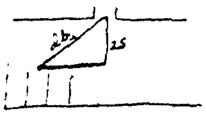
Dimensions in feet

$db_1 = 61$	$d(w_1 l) = 70$	$d(sw_1) = 70$
$db_2 = 54$	$d(w_2 l) = 70$	$d(sw_2) = 70$
$db_3 = 47$	$d(w_3 l) = 70$	$d(sw_3) = 70$
$db_4 = 41$	$d(w_4 l) = 70$	$d(sw_4) = 70$
$db_5 = 35$		
$db_6 = 30$	$d(lw_1) = 70$	
$db_7 = 26$	$d(lw_2) = 70$	
$db_8 = 25$	$d(lw_3) = 70$	
$db_9 = 26$	$d(lw_4) = 70$	
$db_{10} = 30$		
$db_{11} = 35$		
$db_{12} = 41$		
$db_{13} = 47$		
$db_{14} = 54$		
$db_{15} = 61$		

Assume: W_1 and W_3 have wheeled canisters
W_2 and W_4 have non-wheeled canisters
W_1 and W_2 use dock 2
W_3 and W_4 use dock 1

No loadout time penalty for any bays

Forklift travel rate: loaded = 2 mph = 3 fps
unloaded = 3 mph = 4.5 fps



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DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 19 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE I
BY: mwk DATE: 7-13-1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

		$l(aw_1)$ ft	$l(lw_1)$ ft	$l(b_i)$ ft	rate empty fps	TIME sec	$l(b_i)$ ft	$l(w_1 l)$ ft	rate loaded fps	TIME sec	TIME constant sec	TIME penalty sec	Σ TIME sec
W1	b-1	70	-	61	4.5	[redacted]	61	70	3	[redacted]	[redacted]	[redacted]	283
	b-2	-	70	54	〃	[redacted]	54	〃	〃	[redacted]	[redacted]	[redacted]	279
	b-3	-	70	47	〃	[redacted]	47	〃	〃	[redacted]	[redacted]	[redacted]	275
	b-4	-	70	41		[redacted]	41	〃	〃	[redacted]	[redacted]	[redacted]	272
	b-5	-	70	35	〃	[redacted]	35	〃	〃	[redacted]	[redacted]	[redacted]	268
	b-6	-	70	30	〃	[redacted]	30	〃	〃	[redacted]	[redacted]	[redacted]	265
	b-7	-	70	26	〃	[redacted]	26	〃	〃	[redacted]	[redacted]	[redacted]	263
	b-8	-	70	25	〃	[redacted]	25	〃	〃	[redacted]	[redacted]	[redacted]	263
	b-9	-	70	26	〃	[redacted]	26	〃	〃	[redacted]	[redacted]	[redacted]	263
	b-10	-	70	30	〃	[redacted]	30	〃	〃	[redacted]	[redacted]	[redacted]	265
	b-11	-	70	35	〃	[redacted]	35	〃	〃	[redacted]	[redacted]	[redacted]	268
	b-12	-	70	41	〃	[redacted]	41	〃	〃	[redacted]	[redacted]	[redacted]	272
	b-13	-	70	47	〃	[redacted]	47	〃	〃	[redacted]	[redacted]	[redacted]	275
	b-14	-	70	54	〃	[redacted]	54	〃	〃	[redacted]	[redacted]	[redacted]	279
	b-15	-	70	61	〃	[redacted]	61		〃	[redacted]	[redacted]	[redacted]	283

		$l(lw_2)$ ft	$l(b_i)$ ft	rate empty fps	TIME sec	$l(b_i)$ ft	$l(w_2 l)$ ft	rate loaded fps	TIME sec	TIME constant sec	Σ TIME sec
W2	b1	70	61	4.5	[redacted]	61	70	3	[redacted]	[redacted]	258
	b2	〃	54	〃	[redacted]	54	〃	〃	[redacted]	[redacted]	254
	b3	〃	47	〃	[redacted]	47	〃	〃	[redacted]	[redacted]	250
	b4	〃	41	〃	[redacted]	41	〃	〃	[redacted]	[redacted]	247
	b5	〃	35		[redacted]	35	〃	〃	[redacted]	[redacted]	243
	b6	〃	30	〃	[redacted]	30	〃	〃	[redacted]	[redacted]	240
	b7	〃	26	〃	[redacted]	26	〃	〃	[redacted]	[redacted]	238
	b8	〃	25	〃	[redacted]	25	〃	〃	[redacted]	[redacted]	238
	b9	〃	26	〃	[redacted]	26	〃	〃	[redacted]	[redacted]	239
	b10	〃	30	〃	[redacted]	30	〃	〃	[redacted]	[redacted]	240
	b11	〃	35	〃	[redacted]	35	〃	〃	[redacted]	[redacted]	243
	b12		41	〃	[redacted]	41	〃		[redacted]	[redacted]	247
	b13		47	〃	[redacted]	47	〃	〃	[redacted]	[redacted]	250
	b14	〃	51	〃	[redacted]	51			[redacted]	[redacted]	254
	b15	〃	61		[redacted]	61	〃	〃	[redacted]	[redacted]	258

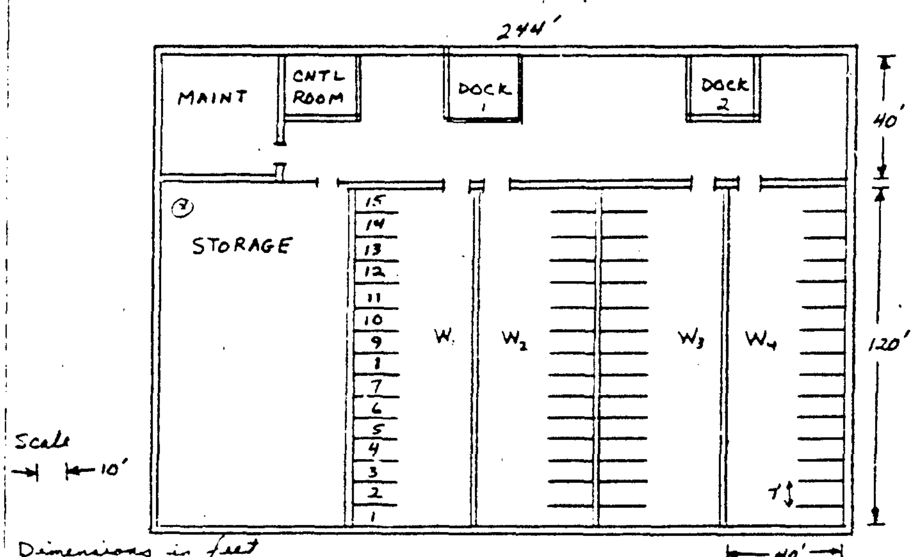
$\underbrace{\Sigma\ 4073 \qquad \Sigma\ 3698}_{\Sigma\ 7771}$

8-20 lead time 420

$\left.\begin{array}{l}\Sigma\ 7771 \\ \text{lead time } 420\end{array}\right\}\ \Sigma = 8191\ \text{sec} = 2.28\ \text{hrs}$

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE LOADOUT 2
BY: mb DATE: 7-12-1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

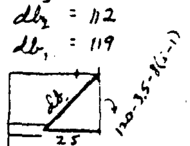


Dimensions in feet

$db_{15} = 25$	$d(w_1 l) = 40$	$d(sw_1) = 110$
$db_{14} = 28$	$d(w_2 l) = 40$	$d(sw_2) = 120$
$db_{13} = 32$	$d(w_3 l) = 40$	$d(sw_3) = 190$
$db_{12} = 38$	$d(w_4 l) = 40$	$d(sw_4) = 210$
$db_{11} = 44$		
$db_{10} = 51$	$d(lw_1) = 40$	
$db_9 = 58$	$d(lw_2) = 40$	
$db_8 = 65$	$d(lw_3) = 40$	
$db_7 = 73$	$d(lw_4) = 40$	
$db_6 = 80$		
$db_5 = 88$		
$db_4 = 96$		
$db_3 = 104$		
$db_2 = 112$		
$db_1 = 119$		

Removal starts with bay 1 and progresses to bay 15

Assume: W_1 and W_3 have wheeled canisters
W_2 and W_4 have non-wheeled canisters
W_1 and W_2 use dock 1
W_3 and W_4 use dock 2
Time penalty for removal from b_{14} and b_{15} in W_1 and W_3 is 90 seconds
Forklift travel rate: loaded = 2 mph = 3 fps
unloaded = 3 mph = 4.5 fps



SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 21 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE 2
BY: [illegible] DATE: 7-12 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

		d(a w)	d(ℓ w)	d(b_i)	rate empty	TIME	d(b_i)	d(w ℓ)	rate loaded	TIME	TIME constant	TIME penalty	Σ TIME
		ft	ft	ft	fps	sec	ft	ft	fps	sec	sec	sec	sec
W1	b1	110	-	119	4.5	[illegible]	119	40	3	[illegible]	[illegible]	-	314
	b2	-	40	112	4.5	[illegible]	112	40	3	[illegible]	[illegible]	-	295
	b3	-	40	104	4.5	[illegible]	104	40	3	[illegible]	[illegible]	-	[illegible]
	b4	-	40	96	4.5	[illegible]	96	40	3	[illegible]	[illegible]	-	285
	b5	-	40	88	4.5	[illegible]	88	40	3	[illegible]	[illegible]	-	291
	b6	-	40	80	4.5	[illegible]	80	40	3	[illegible]	[illegible]	-	277
	b7	-	40	73	4.5	[illegible]	73	40	3	[illegible]	[illegible]	-	272
	b8	-	40	65	4.5	[illegible]	65	40	3	[illegible]	[illegible]	-	267
	b9	-	40	58	4.5	[illegible]	57	40	3	[illegible]	[illegible]	-	265
	b10	-	40	51	4.5	[illegible]	51	40	3	[illegible]	[illegible]	-	260
	b11	-	40	44	4.5	[illegible]	44	40	3	[illegible]	[illegible]	-	257
	b12	-	40	38	4.5	[illegible]	38	40	3	[illegible]	[illegible]	-	253
	b13	-	40	32	4.5	[illegible]	32	40	3	[illegible]	[illegible]	-	250
	b14	-	40	28	4.5	[illegible]	28	40	3	[illegible]	[illegible]	[illegible]	238
	b15	-	40	25	4.5	[illegible]	25	40	3	[illegible]	[illegible]	[illegible]	334

		d(ℓ w2)	d(b_i)	rate empty	TIME	d(b_i)	d(w2 ℓ)	rate loaded	TIME	TIME constant	Σ TIME
		ft	ft	fps	sec	ft	ft	fps	sec	sec	sec
W2	b1	40	119	4.5	[illegible]	119	40	3	[illegible]	[illegible]	272
	b2	40	112	4.5	[illegible]	112	40	3	[illegible]	[illegible]	270
	b3	40	104	4.5	[illegible]	104	40	3	[illegible]	[illegible]	265
	b4	40	96	4.5	[illegible]	96	40	3	[illegible]	[illegible]	260
	b5	40	88	4.5	[illegible]	88	40	3	[illegible]	[illegible]	256
	b6	40	80	4.5	[illegible]	80	40	3	[illegible]	[illegible]	252
	b7	40	73	4.5	[illegible]	73	40	3	[illegible]	[illegible]	248
	b8	40	65	4.5	[illegible]	65	40	3	[illegible]	[illegible]	243
	b9	40	58	4.5	[illegible]	58	40	3	[illegible]	[illegible]	240
	b10	40	51	4.5	[illegible]	51	40	3	[illegible]	[illegible]	235
	b11	40	44	4.5	[illegible]	44	40	3	[illegible]	[illegible]	232
	b12	40	38	4.5	[illegible]	38	40	3	[illegible]	[illegible]	229
	b13	40	32	4.5	[illegible]	32	40	3	[illegible]	[illegible]	225
	b14	40	28	4.5	[illegible]	28	40	3	[illegible]	[illegible]	223
	b15	40	25	4.5	[illegible]	25	40	3	[illegible]	[illegible]	221

Σ 4242 $\qquad$ Σ 3671

$\underbrace{\Sigma\ 4242 \qquad \Sigma\ 3671}$

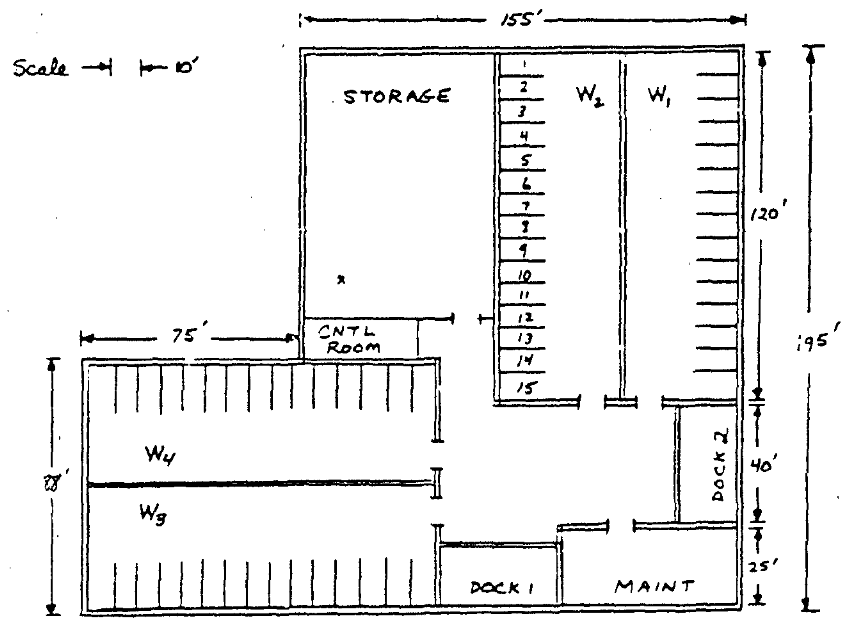
Σ 7913
8-22 leadtime 420

Σ = 8330 sec = 2.31 hrs.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 22 OF 34

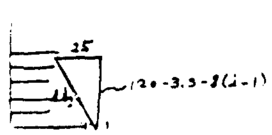
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE LOADOUT 3
BY: mvb DATE: 7-13 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___



Dimensions in feet

$db_1 = 119$	$d(w_1 l) = 45$	$d(aw_1) = 155$
$db_2 = 112$	$d(w_2 l) = 65$	$d(aw_2) = 145$
$db_3 = 104$	$d(w_3 l) = 45$	$d(aw_3) = 135$
$db_4 = 96$	$d(w_4 l) = 65$	$d(aw_4) = 115$
$db_5 = 88$		
$db_6 = 80$	$d(lw_1) = 45$	
$db_7 = 73$	$d(lw_2) = 65$	
$db_8 = 65$	$d(lw_3) = 45$	
$db_9 = 58$	$d(lw_4) = 65$	
$db_{10} = 51$		
$db_{11} = 44$		
$db_{12} = 38$		
$db_{13} = 32$		
$db_{14} = 28$		
$db_{15} = 25$		

$\boxed{\text{Assume}}$: W_1 and W_3 have wheeled canisters
W_2 and W_4 have non-wheeled canisters
W_1 and W_2 use dock 2
W_3 and W_4 use dock 1
Time penalty for removal from b_{14} and b_{15} in W_1 and W_3 is 90 seconds.
Forklift travel rates:
loaded = 2 mph = 3 fps
unloaded = 3 mph = 4.5 fps
Removal starts with bay 1 and progresses to bay 15.



SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 23 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE 3
BY: [illegible] DATE: 7-13- 19 82 CHECKED BY: DATE CHECKED:

	$\ell(\ell w_1)$ ft	$\ell(\ell w_1)$ ft	$\ell(b_i)$ ft	rate empty fps	TIME sec	$\ell(b_i)$ ft	$\ell(w\ell)$ ft	rate loaded fps	TIME sec	TIME constant sec	TIME penalty sec	Σ TIME sec
W1 b_1	155	-	119	45	[illegible]	119	45	3	[illegible]	[illegible]	[illegible]	326
b_2	-	45	112	"	[illegible]	112	"	"	[illegible]	[illegible]	[illegible]	297
b_3	-	"	104	"	[illegible]	104	"	"	[illegible]	[illegible]	[illegible]	293
b_4	-	"	96	"	[illegible]	96	"	"	[illegible]	[illegible]	[illegible]	289
b_5	-	"	88	"	[illegible]	88	"	"	[illegible]	[illegible]	[illegible]	284
b_6	-	"	80	"	[illegible]	80	"	"	[illegible]	[illegible]	[illegible]	279
b_7	-	"	73	"	[illegible]	73	"	"	[illegible]	[illegible]	[illegible]	275
b_8	-	"	65	"	[illegible]	65	"	"	[illegible]	[illegible]	[illegible]	271
b_9	-	"	58	"	[illegible]	58	"	"	[illegible]	[illegible]	[illegible]	267
b_{10}	-	"	51	"	[illegible]	51	"	"	[illegible]	[illegible]	[illegible]	263
b_{11}	-	"	44	"	[illegible]	44	"	"	[illegible]	[illegible]	[illegible]	260
b_{12}	-	"	38	"	[illegible]	38	"	"	[illegible]	[illegible]	[illegible]	256
b_{13}	-	"	32	"	[illegible]	32	"	"	[illegible]	[illegible]	[illegible]	253
b_{14}	-	"	28	"	[illegible]	28	"	"	[illegible]	[illegible]	[illegible]	250
b_{15}	-	"	25	"	[illegible]	25	"	"	[illegible]	[illegible]	[illegible]	249

Σ 4112

	$\ell(\ell w_2)$ ft	$\ell(b_i)$ ft	rate empty fps	TIME sec	$\ell(b_i)$ ft	$\ell(w_2\ell)$ ft	rate loaded fps	TIME sec	TIME constant sec	Σ TIME sec
W2 b_1	65	119	45	[illegible]	119	65	3	[illegible]	[illegible]	287
b_2	"	112		[illegible]	112	"	"	[illegible]	[illegible]	283
b_3	"	104		[illegible]	104	"	"	[illegible]	[illegible]	279
b_4	"	96		[illegible]	96	"	"	[illegible]	[illegible]	275
b_5	"	88		[illegible]	88		"	[illegible]	[illegible]	270
b_6	"	80		[illegible]	80	"	"	[illegible]	[illegible]	265
b_7	"	73		[illegible]	73	"	"	[illegible]	[illegible]	[illegible]
b_8	"	65		[illegible]	65	"	"	[illegible]	[illegible]	[illegible]
b_9	"	58		[illegible]	58	"	"	[illegible]	[illegible]	253
b_{10}	"	51		[illegible]	51	"	"	[illegible]	[illegible]	250
b_{11}	"	44		[illegible]	44	"	"	[illegible]	[illegible]	245
b_{12}	"	38	"	[illegible]	38	"	"	[illegible]	[illegible]	242
b_{13}	"	32	"	[illegible]	32	"	"	[illegible]	[illegible]	[illegible]
b_{14}	"	28	"	[illegible]	28	"	"	[illegible]	[illegible]	237
b_{15}	"	25	"	[illegible]	25	"	"	[illegible]	[illegible]	215

Σ 3879

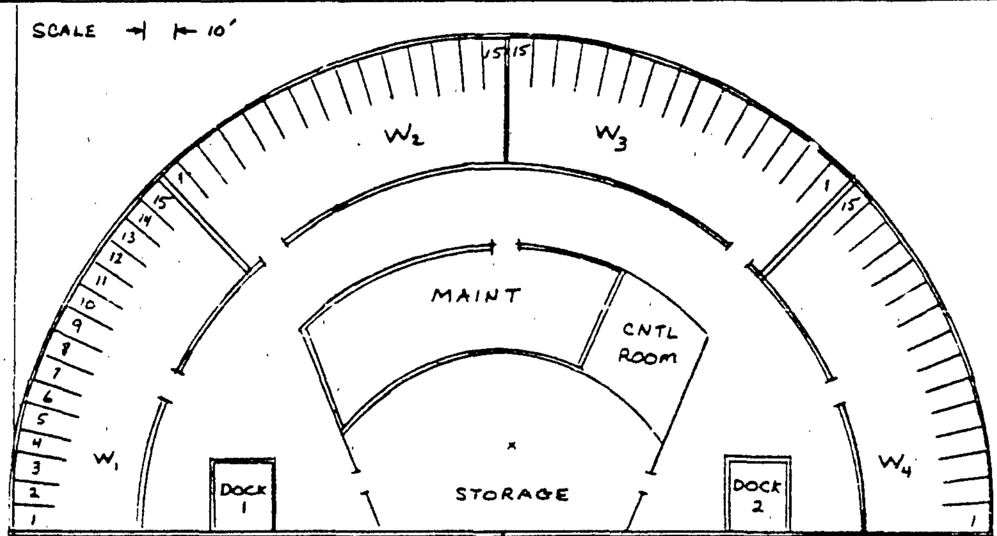
Σ 7991
8-24 leadtime 420

$\Sigma = 8411$ sec $= 2.34$ hrs

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 24 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE LOADOUT 4
BY: mwb DATE: 7-13-1982 CHECKED BY: DATE CHECKED: 19



For W_1, W_4	For W_2, W_3
$db_1 = 61$	$= 30$
$db_2 = 54$	$= 30$
$db_3 = 47$	$= 30$
$db_4 = 41$	$= 33$
$db_5 = 35$	$= 38$
$db_6 = 30$	$= 42$
$db_7 = 26$	$= 49$
$db_8 = 25$	$= 57$
$db_9 = 26$	$= 61$
$db_{10} = 30$	$= 67$
$db_{11} = 35$	$= 73$
$db_{12} = 41$	$= 80$
$db_{13} = 47$	$= 86$
$db_{14} = 54$	$= 93$
$db_{15} = 61$	$= 99$
(from layout 4 analysis)	(measured)

$d(w_1 l) = 60 = d(l w_1)$ $\quad d(s w_1) = 140$

$d(w_2 l) = 100 = d(l w_2)$ $\quad d(s w_4) = 140$

$d(w_3 l) = 100 = d(l w_3)$

$d(w_4 l) = 60 = d(l w_4)$

Assume: W_1 and W_4 have wheeled canisters
W_2 and W_3 have non-wheeled canisters
W_1 and W_2 use dock 1
W_3 and W_4 use dock 2
No loadout time penalty for any bays
Forklift travel rates:
loaded - 2 mph = 3 fps
unloaded = 3 mph = 4.5 fps.
Removal starts with bay 1 and progresses to bay 15.

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 25 OF 31

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE 4
BY: mwb DATE: 7-14 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

	l (aw) ft	l (lw_1) ft	l (b_i) ft	rate empty fps	TIME sec	l (b_i) ft	l (w_1l) ft	rate loaded fps	TIME sec	TIME constant sec	TIME penalty sec	Σ TIME sec
W1 l-1	40	-	61	45	[illegible]	61	[illegible]	3	[illegible]	[illegible]	[illegible]	295
l-2	-	62	54	"	[illegible]	[illegible]	"	"	[illegible]	[illegible]	[illegible]	273
l-3	-	"	47		[illegible]	47		"	[illegible]	[illegible]	[illegible]	270
l-4	-	"	-		[illegible]	41		"	[illegible]	[illegible]	[illegible]	262
l-5	-	"	35		[illegible]	35	"	"	[illegible]	[illegible]	[illegible]	[illegible]
l-6	-	"	30		[illegible]	30	"	"	[illegible]	[illegible]	[illegible]	[illegible]
l-7	-	"	26	"	[illegible]	26	"	"	[illegible]	[illegible]	[illegible]	259
l-8	-	"	25		[illegible]	25	"	"	[illegible]	[illegible]	[illegible]	257
l-9	-	"	26		[illegible]	26	"	"	[illegible]	[illegible]	[illegible]	258
l-10	-	"	30		[illegible]	30	"	"	[illegible]	[illegible]	[illegible]	260
l-11	-	"	35	"	[illegible]	35	"	"	[illegible]	[illegible]	[illegible]	263
l-12	-	"	41	"	[illegible]	41	"	"	[illegible]	[illegible]	[illegible]	266
l-13	-	"	47	"	[illegible]	47	"	"	[illegible]	[illegible]	[illegible]	270
l-14	-	"	54	"	[illegible]	54	"	"	[illegible]	[illegible]	[illegible]	[illegible]
l-15	-	"	61	"	[illegible]	61	"	"	[illegible]	[illegible]	[illegible]	277

Σ 4009

	l (lw_2) ft	l (b_i) ft	rate empty fps	TIME sec	l (b_i) ft	l (w_2l) ft	rate loaded fps	TIME sec	TIME constant sec	Σ TIME sec
W2 l-1	100	30	45	[illegible]	30	100	3	[illegible]	[illegible]	[illegible]
l-2	"	30	"	[illegible]	30	"	"	73	[illegible]	[illegible]
l-3	"	30		[illegible]	30	"	"	73	[illegible]	[illegible]
l-4		33		[illegible]	33			[illegible]	[illegible]	[illegible]
l-5		38		[illegible]	38			[illegible]	[illegible]	[illegible]
l-6		42		[illegible]	42			[illegible]	[illegible]	264
l-7	"	49		[illegible]	49	"	"	[illegible]	[illegible]	[illegible]
l-8	"	57	"	[illegible]	57		"	[illegible]	[illegible]	[illegible]
l-9		61	"	[illegible]	61	"		[illegible]	[illegible]	[illegible]
l-10	"	67	"	[illegible]	67	"		[illegible]	[illegible]	[illegible]
l-11		73		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]
l-12		80	"	[illegible]	80			[illegible]	[illegible]	[illegible]
l-13		86		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]
l-14	"	93		[illegible]	[illegible]			[illegible]	[illegible]	292
l-15	"	99		[illegible]	99	"		[illegible]	[illegible]	295

Σ 4090

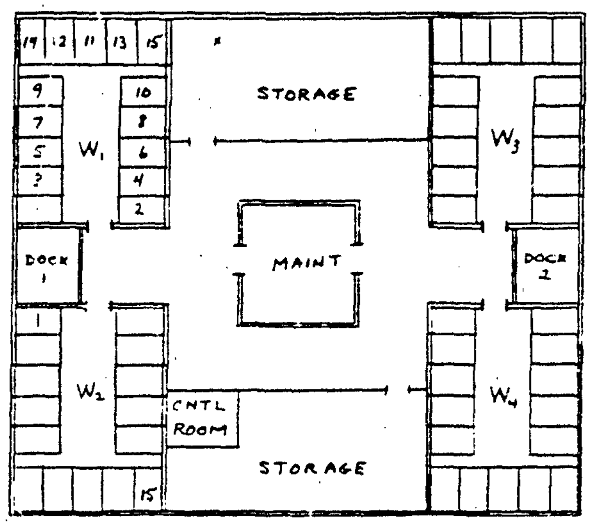
Σ 8099
lead time 420 — Σ = 8519 sec = 2.37 hrs

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO 26 OF 31

PROJECT NO 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE LOADOUT 5
BY rwb DATE 7-14 1982 CHECKED BY: ______ DATE CHECKED ______ 19 __

Scale ⇥ ⊢ 10'



$db_1 = 6$ $lw_1 = w_1 l = 35$
$db_2 = 6$ $lw_2 = w_2 l = 35$
$db_3 = 16$
$db_4 = 16$ $sw_1 = sw_3 = 110$
$db_5 = 26$
$db_6 = 26$
$db_7 = 36$
$db_8 = 36$
$db_9 = 46$
$db_{10} = 46$
$db_{11} = 46$
$db_{12} = 46$
$db_{13} = 46$
$db_{14} = 46$
$db_{15} = 46$

Assumptions: W_1 and W_3 have wheeled canisters
W_2 and W_4 have non-wheeled canisters
W_1 and W_2 use dock 1
W_3 and W_4 use dock 2
No loadout time penalties for any bays

Forklift travel rates: loaded = 2 mph = 3 fps
unloaded = 3 mph = 4.5 fps
Crane travel rates: longitudinal = 1.5 fps
lateral = 1.5 fps
vertical = 0.25 fps

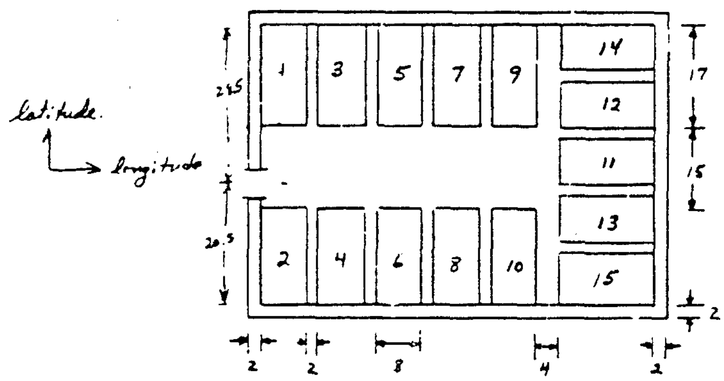
Removal starts with bay 1 and progresses to bay 15

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

SHEET NO. 27 OF 31

PROJECT NO. 02-7092 SPONSOR CERL
SUBJECT EXAMPLE 5
BY nwb DATE 7-14-1982 CHECKED BY: DATE CHECKED 19

WEAPON BAY
PIT DESIGN



d(lat) bay		d(long) bay	
1	20	1	4
2	12	2	0
3	20	3	10
4	12	4	0
5	20	5	10
6	12	6	0
7	20	7	10
8	12	8	0
9	20	9	10
10	12	10	0
11	4	11	17
12	14	12	17
13	6	13	17
14	24	14	17
15	16	15	17

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF BALLISTICS AND EXPLOSIVES SCIENCES
COMPUTATION SHEET

PROJECT NO 02-7092 SPONSOR CERL
SUBJECT EXAMPLE 5
BY mwf DATE 7-14-1982 CHECKED BY: ______ DATE CHECKED ______ 19__

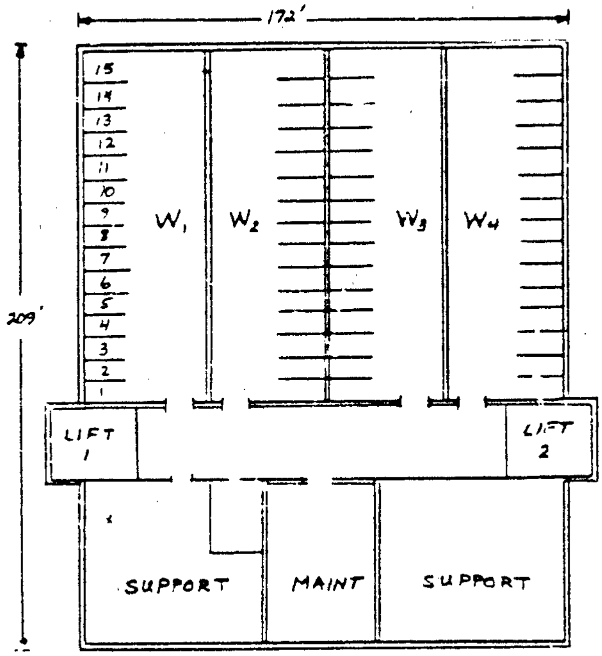
		ℓ(aw) ft	ℓ(lw) ft	ℓ(bi) ft	rate empty fps	TIME sec	ℓ(bi) ft	ℓ(wl) ft	rate loaded fps	TIME sec	TIME constant sec	TIME penalty sec	Σ TIME sec	OVER ℓi(long) ft	ℓi(lat) ft	rate fps	TIME sec	BACK ℓi(long) ft	ℓi(lat) ft	rate fps	TIME sec	TIME constant sec	TIME penalty sec	Σ TIME sec	Max Σ TIME sec
W1	l-1	110	-	6	45	[redacted]	6	35	3	[redacted]	[redacted]	[redacted]	250	4	20	1.5	[redacted]	0	20	1.5	[redacted]	[redacted]	[redacted]	129	250
	l-2	-	25	6		[redacted]	6			[redacted]	[redacted]	[redacted]	233	0	12		[redacted]	0	12		[redacted]	[redacted]	[redacted]	116	233
	l-3	-		16		[redacted]	16			[redacted]	[redacted]	[redacted]	238	10	20		[redacted]	0	20		[redacted]	[redacted]	[redacted]	133	238
	l-4	-		16		[redacted]	16			[redacted]	[redacted]	[redacted]	238	0	12		[redacted]	0	12		[redacted]	[redacted]	[redacted]	116	238
	l-5	-		26		[redacted]	26			[redacted]	[redacted]	[redacted]	244	10	20		[redacted]	0	20		[redacted]	[redacted]	[redacted]	133	244
	l-6	-		26		[redacted]	26			[redacted]	[redacted]	[redacted]	244	0	12		[redacted]	0	12		[redacted]	[redacted]	[redacted]	116	244
	l-7	-		36		[redacted]	36			[redacted]	[redacted]	[redacted]	250	10	20		[redacted]	0	20		[redacted]	[redacted]	[redacted]	133	250
	l-8	-		36		[redacted]	36			[redacted]	[redacted]	[redacted]	250	0	12		[redacted]	0	12		[redacted]	[redacted]	[redacted]	116	250
	l-9	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	10	20		[redacted]	0	20		[redacted]	[redacted]	[redacted]	133	255
	l-10	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	0	12		[redacted]	0	12		[redacted]	[redacted]	[redacted]	116	255
	l-11	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	17	4		[redacted]	17	4		[redacted]	[redacted]	[redacted]	128	255
	l-12	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	-	-		[redacted]	17	14		[redacted]	[redacted]	[redacted]	141	255
	l-13	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	17	6		[redacted]	17	6		[redacted]	[redacted]	[redacted]	130	255
	l-14	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	17	24		[redacted]	17	24		[redacted]	[redacted]	[redacted]	154	255
	l-15	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	255	17	16		[redacted]	17	16		[redacted]	[redacted]	[redacted]	144	255
																									3732
W2	l-1	-	35	6	[illegible]	[redacted]	6	35	3	[redacted]	[redacted]	[redacted]	208												208
	l-2	-		6		[redacted]	6			[redacted]	[redacted]	[redacted]	208												208
	l-3	-		16		[redacted]	16			[redacted]	[redacted]	[redacted]	213												213
	l-4	-		16		[redacted]	16			[redacted]	[redacted]	[redacted]	213												213
	l-5	-		26		[redacted]	26			[redacted]	[redacted]	[redacted]	219												219
	l-6	-		26		[redacted]	26			[redacted]	[redacted]	[redacted]	219												219
	l-7	-		36		[redacted]	36			[redacted]	[redacted]	[redacted]	225												225
	l-8	-		36		[redacted]	36			[redacted]	[redacted]	[redacted]	225												225
	l-9	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
	l-10	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
	l-11	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
	l-12	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
	l-13	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
	l-14	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
	l-15	-		46		[redacted]	46			[redacted]	[redacted]	[redacted]	230												230
																									2240

SAME AS ABOVE

$\Sigma =$ 7492 sec
2.08 hrs

Σ 7072
Lead time 420

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE LOADOUT 6
BY: mrb DATE: 9-8-1982 CHECKED BY: ______ DATE CHECKED ______ 19 ___

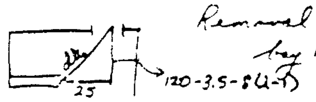


Dimensions in feet:

$d(w_1 l) = 25 = d(lw_1)$ $d(sw) = 60'$
$d(w_2 l) = 45' = d(lw_2)$

$db_1 = 25$
$db_2 = 28$
$db_3 = 32$
$db_4 = 38$
$db_5 = 44$
$db_6 = 51$
$db_7 = 58$
$db_8 = 65$
$db_9 = 73$
$db_{10} = 80$
$db_{11} = 88$
$db_{12} = 96$
$db_{13} = 104$
$db_{14} = 112$
$db_{15} = 119$

Assume: W_1 and W_2 use lift 1
W_3 and W_4 use lift 2
Time penalty for removal from bays 14, 15 is 30 seconds.
Forklift travel rate – loaded = 2 mph = 3 fps
empty = 3 mph = 4.5 fps.
Lift rate = 1 fps for 30 ft.
Removal starts with bay 15 and progresses to bay 1.



SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF ENERGETIC SYSTEMS
COMPUTATION SHEET

SHEET NO. 30 OF 34

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: EXAMPLE 6
BY: mb DATE: 9-8-1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

		$\ell(lw_1)$	$\ell(lw_1)$	$\ell(l_i)$	rate empty	TIME	$\ell(l_i)$	$\ell(w_1\ell)$	rate loaded	TIME	TIME constant	TIME penalty	Σ TIME	$\ell(lw_2)$	$\ell(l_i)$	rate empty	TIME	$\ell(l_i)$	$\ell(w_2\ell)$	rate loaded	TIME	TIME constant	Σ TIME
		ft	ft	ft	fps	sec	ft	ft	fps	sec	sec	sec	sec	ft	ft	fps	sec	ft	ft	fps	sec	sec	sec
W1	l_1	–	25	25	4.5	11	25	25	3	17	350	0	379										
	l_2	–	"	28	"	12	28	"	"	18		"	380										
	l_3	–	"	32	"	13	32	"	"	19			382										
	l_4	–		38	"	14	38			21			385										
	l_5	–		44		15	44			23			388										
	l_6	–		51	"	17	51			25	"		392										
	l_7	–	"	58	"	18	58	"	"	28			396										
	l_8	–	"	65	"	20	65	"	"	30	"	"	400										
	l_9	–		73	"	22	73	"	"	33	"	"	405										
	l_{10}	–	"	80	"	23	80	"	"	35	"	"	408										
	l_{11}	–	"	88	"	25	88	"	"	38	"	"	413										
	l_{12}	–	"	96	"	27	96	"	"	40	"		417										
	l_{13}	–	"	104	"	29	104	"	"	43	"	"	422										
	l_{14}	–		112	"	30	112	"	"	46	350	30	456										
	l_{15}	60	"	119	"	32	119	"	"	48	305	30	415										
													6037										
W2	l_1	–	45	25	4.5	16	25	45	3	23	350	0	389										
	l_2	–	"	29	"	16	29	"	"	24	"	"	390										
	l_3	–		32	"	17	32	"	"	26		"	293										
	l_4	–	"	38	"	18	38	"	"	28		"	296										
	l_5	–	"	44		20	44	"	"	30	"	"	400										
	l_6	–		51	"	21	51	"	"	32		"	403										
	l_7	–	"	58	"	23	58			34			407										
	l_8	–	"	65	"	24	65		"	37			411										
	l_9	–	"	73	"	26	73			39			415										
	l_{10}	–	"	80	"	29	80	"	"	42	"	"	420										
	l_{11}	–	"	88	"	30	88			44			424										
	l_{12}	–	"	96	"	31	96			47			428										
	l_{13}	–	"	104		33	104			50			433										
	l_{14}	–	"	112		35	112	"	"	52		30	467										
	l_{15}	–	"	119	"	36	119	"	"	55		30	471										
													6247										

$$\underbrace{\Sigma \qquad\qquad \Sigma}$$

$$\left.\begin{array}{r} \Sigma\ 12284 \\ \text{leadtime}\ \underline{\underline{420}} \end{array}\right\} \Sigma = 12704\ \text{sec} = 3.53\ \text{hr}$$

LOADOUT TIMES FOR 6 CONCEPTS SELECTED

ASSUME EACH BAY LOADING OUT SIMULTANEOUSLY
SO LOADOUT TIME = TIME FOR SLOWEST BAY.

CONCEPT 1 - Use times from Example 1, bay no 2.

Time = 3698 sec
+ 420 sec leadtime
4118
~ 1.14 hrs

CONCEPT 2 - Use times from Example 1, bay no. 1
CONCEPT 5

Time = 4073 sec
+ 420 leadtime
4493 sec
~ 1.25 hrs.

CONCEPT 3 - Use times from Example 6, bay no. 1

Time = 6037 sec
- 100 sec (shorter bays)
+ 420 sec (leadtime)
6357 sec
~ 1.77 hrs.

CONCEPT 4 - Use times from Example 6, bay no. 2
CONCEPT 6

Time = 6247 sec
+ 420 sec leadtime
6667 sec
~ 1.85 hrs.

APPENDIX 9

SURVIVABILITY

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COMPUTATION SHEET

SHEET NO. ___ OF ___

PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: Force-Time for 747 Crash
BY: Philip T. Hill DATE: 26 Sept 19 82 CHECKED BY: ___ DATE CHECKED: ___ 19 ___

CONTENTS -

LARGE AIRCRAFT CRASH

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COMPUTATION SHEET

SHEET NO. 1 OF 7

PROJECT NO. 02-7092-001 SPONSOR CERL
SUBJECT Force-Time for 747 Crash
BY W.E. Baker DATE 2/24 19 82 CHECKED BY [signature] DATE CHECKED: 6/25 1982

Analysts and designers of nuclear power plants have considered the effects of aircraft crash on these plants, and have developed ways of estimating the force-time histories for crashes of a spectrum of aircraft into rigid walls. These estimates are reported in a number of papers in the SMiRT (Structural Mechanics in Reactor Technology) Conferences.

One paper in particular is useful for our purpose of estimating dynamic loads for a 747 crash.[1] The authors compare the force-time histories for crash of a number of different aircraft, with several curves being given for the 707 aircraft, but none for the 747. Fig 1 is taken from Ref. 1, and shows four force-time crash curves for the 707 aircraft.

1 G. Larsson & P. Lundsager, "On the Response of a Reactor Building to Aircraft Crash", Transactions of the 4th International Conference on Structural Mechanics in Reactor Technology, 1977, San Francisco, CA, Paper J9/4.

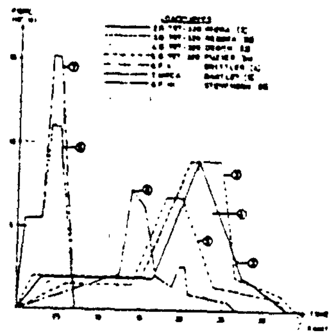

Fig 1. Force-Time Curves for Aircraft Crashes (Ref. 1)

The 707 aircraft is very similar in configuration to the 747. Both have rather long cylindrical fuselages, swept low wings and horizontal stabilizers with the same sweep angles, swept vertical stabilizer, and four engines mounted on pylons below the wings. To predict the 747 force-time history in a crash, we assume that it is essentially a replica of the 707, to a larger scale, and use similitude relations to scale an appropriate curve in Fig. 1.

Some general characteristics of the two aircraft appear in Table 1, from Ref. 1.

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SHEET NO. 3 OF 7

PROJECT NO. 02-7092-001 SPONSOR: CERL
SUBJECT: Force-Time for 747 Crash
BY: W. E. Baker DATE 6/24 1982 CHECKED BY: PTN DATE CHECKED: 6/25 1982

Table 1. Aircraft Characteristics

Aircraft	Wing Span, m	Fus. Length, m	Fus. Dia., m	Take-Off Wt, kg	Ldg. Wt, kg
B 707	44.4	44.4	)	150,000	112,000
B 747	59.6	68.4	6.5	372,000	286,000

In "replica" scale modeling of structural crushing under impact loads, Ref. 2 shows that the "model" and "prototype" structures should be exact geometric scale models of each other, and employ all of the same materials in the same locations. This is, of course, not exactly true when comparing a 707 to a 747. But, neglecting for the moment deviations from exact replication, we can use the inferences of the replica modeling law to scale the force-time history of the crashing 707 to a 747. If λ is the geometric scale factor obtained by scaling any comparable lengths for the two aircraft, then the law states that times scale by

2. W. E. Baker, P. S. Westine & F. T. Dodge, "Similarity Methods in Engineering Dynamics", Hayden Books, New Rochelle, N.J., 1973.

the same scale factor λ as do lengths, velocities are unchanged, weights or masses scale as λ^3, and forces scale as λ^2 (See Ref. 2)

What should λ be, when scaling up from a 707 to a 747? From Table 1, we can get several values by making length ratios and by taking the cube roots of mass ratios. These factors are given in Table 2.

Table 2. Geometric Scale Factors, 747/707

Parameter	Symbol	Value
Wing span ratio	λ_S	1.34
Fuselage length ratio	λ_L	1.54
Fuselage diameter ratio	λ_D	1.70
(Take-off mass ratio)$^{1/3}$	λ_{TO}	1.35
(Landing mass ratio)$^{1/3}$	λ_{LG}	1.37

To scale the force-time history of a 707 to a 747, it seems appropriate to scale the time by λ_L, because the duration

of the crash force should be proportional to fuselage length. But, to scale the force amplitudes, a scale factor related to mass seems more appropriate. So, we assume that $\lambda_t = \lambda_L = \underline{1.54}$, and take an average between the two values based on mass scaling for

$$\lambda_F = \left(\frac{\lambda_c + \lambda_{LG}}{2}\right)^2 = \underline{1.85}.$$

Figure 1 shows four curves for force-time histories for a 707 crash. We scale the one labeled (3) as a conservative upper limit. Table 3 gives F, t coordinates from this curve, and the values scaled up to a 747, using the scale factors for force and time listed above.

Table 3

Force-Time Coordinates for 707 and 747 Aircraft

707		747	
F, 10^7 N	t, s.	F, 10^7 N	t, s.
0	0	0	0
1.9	0.018	3.5	0.028
1.9	0.153	3.5	0.236
9.9	0.208	18.3	0.320
9.9	0.245	[illegible]	0.377
1.9	0.265	[illegible]	0.408
1.0	0.318	1.9	0.490
0	0.340	0	0.524

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SUBJECT Force-Time for 747 Crash
BY W.E. Baker DATE 2/25 19 82 CHECKED BY: AN DATE CHECKED 6/25 1982

The force-time history for the 747 from Table 3 is plotted in Fig 1. We can use this plot as a conservative (upper limit) forcing function for a 747 crash, because it is based on head-on crash into a rigid wall. Earth cover or oblique impact can only attenuate the loads.

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SHEET NO 7 OF 7

PROJECT NO 02-7092-001 SPONSOR CERL
SUBJECT Force-Time for 747 Crash
BY W. E. Baker DATE 6/25 19 82 CHECKED BY PAN DATE CHECKED 6/25 1982

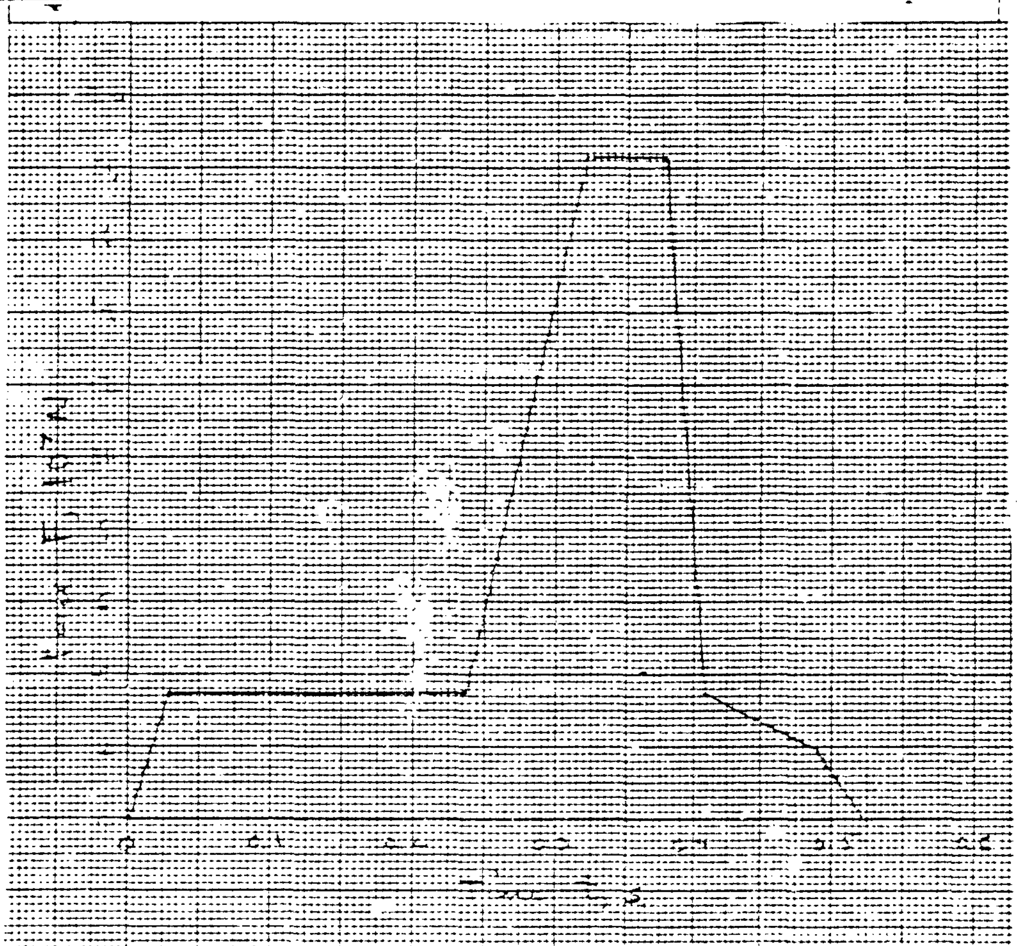

Fig 1.
Force-Time History for Crash of a 747 Aircraft

Dr. Baker used replica modeling techniques to develop a force-time history for a 747 crash into a rigid wall based upon similar histories for 707 aircraft. Time durations and peak forces can be determined in an alternate manner as a check. Important aircraft parameters are shown in Table 1.[1]

TABLE 1. Aircraft Parameters

Aircraft Type	Wing Span (m)	Length (m)	Diameter (m)	Max. Take-off weight (kg)
B-720	39.9	39.2	4.0	106,160
B707-320	44.4	44.4	3.8	151,300
B747-200B	59.6	68.4	6.8	351,000
B747-200C	59.6	68.4	6.8	372,000
F4	11.7	17.8	2.0	20,865
MRCA	8.6-13.9	14.1	1.8	18,145
F111	10.3-21.9	20.8	1.9	41,500

Reference 2 details force-time curves for several aircraft with impact data given in Table 2.

1 Jane's All the World's Aircraft 1978-79, Second Edition, John WR Taylor Editor.

2. Iversen, G. and Lundberg, P., "On the Response of a Reactor Building and its Equipment to Aircraft Crash", Transactions of the 4th International Conference on Structural Mechanics in Reactor Technology, Vol J(6). Loading Conditions and Structural Analysis of Reactor Containment, 15-19 August 77.

TABLE 2

IMPACT DATA
(from Reference 2)

Aircraft Type	Aircraft Mass 1,000 kg	Impact Speed (m/s)	Impact Area m^2	Peak Load 10^7N	[illegible]	Momentum M·v 10^6 Ns	Impulse $\int F(t)dt$ 10^6 Ns
B720	72.4	103	18-36	7.1	-	7.46	7.37
B707-320	97.6	103	18-36	8.9	.35	10.1	9.24
B707-320	--	103	28	8.8	.36	--	11.4
B707-320	90.0	103	10-40	8.8	.35	9.27	9.12
B707-320	100.0	83	28	6.8	.35	8.83	7.26
F4	20.0	215	7	10.8	.57	4.30	4.31
MRCA	25.0	215	7	15.1	.67	5.38	5.35
F111	41.5	89	--	7.3	.27	3.69	4.91

Peak force during the aircraft crash should vary according to the specific impact momentum (momentum per unit area, M·v/A). Using the impact data and aircraft characteristics giving specific momentum and peak force are shown in Figure 1. For 707 aircraft impacting at speeds between 100 and 120 m/sec, peak forces of 12. to 17. X10^7 N can be expected, depending upon aircraft weight. Duration of the load will vary with the length and

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SHEET NO. 3 OF 4

PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: Force-Time for 747 Crash
BY: Phillip T. [illegible] DATE: 6/26 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

stiffness of the aircraft fuselage. Figure 2 plots fuselage length versus load duration for the aircraft data given. The upper curve is expected to be more representative of the 747 aircraft because the 707, similar in stiffness to the 747, is the major influence on the curve development. Using the upper curve, the load duration for the 747 aircraft is approximately .49 seconds. Thus, load-time histories for 747 aircraft crashing into rigid walls can expect peak forces and load durations near the following:

Peak Force – $12-17 \times 10^7$ N.
Load Duration – $\approx$ .49 seconds.

These values are very near those developed by Dr. Baker. I recommend using the force-time curve developed using replica modeling.

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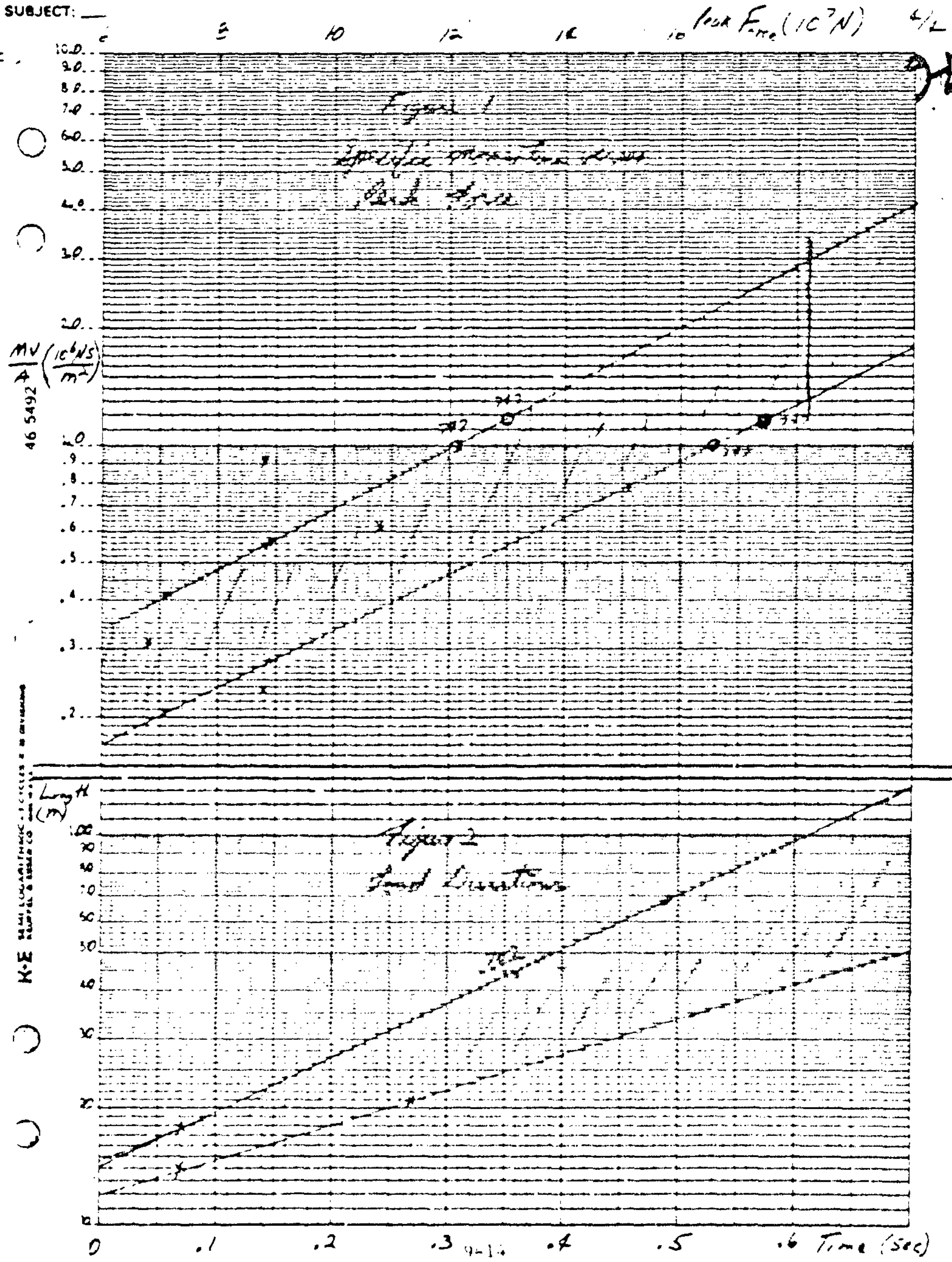
SHEET NO. 4 OF 4

PROJECT NO.: 02-7092 SPONSOR: CERL

SUBJECT:

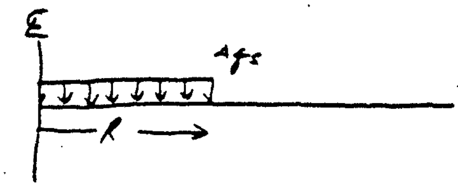


9-14

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Soil Pressure Attenuation
BY: [signature] DATE: 9 Aug 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ___

A Boussinesq solution for loading at the surface of an elastic half-space was used to calculate the attenuation of the aircraft impact stresses through soil. Although a static solution, for the relatively long load durations it should represent the stress attenuation due to geometric dispersion.

Load –



r for a 747 = 3.4 m = 11.12 ft.

Peak Force = 18.3×10^7 N = 4.114×10^7 lb

$$\Delta q_s = \frac{F}{A} = \frac{4.114 \times 10^7}{\pi (11.12)^2\, 144} = 735 \text{ psi}$$

The chart shown on page 2 was used to determine stress coefficients at 5 ft. increments vertically and horizontally. For example the stress coefficient at 25' depth, 10' horizontally from the centerline is 0.18. Stresses calculated are shown on page 3 (.18 × 735 = 132 for the example) and illustrated graphically on page 4.

4.114 x10^7 lb

π (11.12)^2 144 = 135 psi

2/4

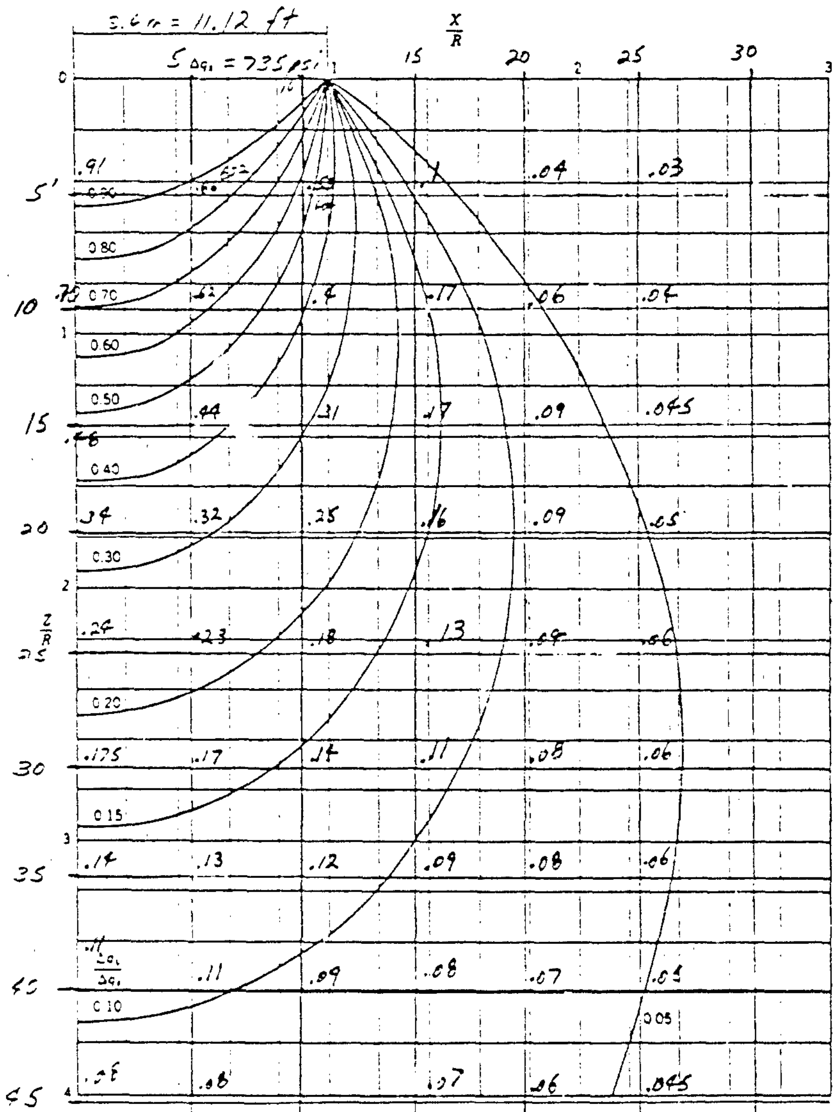


Fig 8.4 Vertical stresses induced by uniform load on circular area.

It is a very tedious matter to obtain the elastic solution for a given loading and set of boundary conditions. In this book, we are concerned not with how to obtain solutions but rather with how to use these solutions. This section presents several solutions in graphical form.

Uniform load over a circular area. Figures 8.4 and 8.5 give the stresses caused by a uniformly distributed normal stress Δq_s acting over a circular area of radius R on the surface of an elastic half-space.[3] These stresses must be added to the initial geostatic stresses. Figure 8.4 gives

[3] In general, the stresses computed from the theory of elasticity are functions of Poisson's ratio μ. This quantity will be defined in Chapter 12. However, vertical stresses resulting from normal stresses applied to the surface are always independent of μ, and stresses caused by a strip load are also independent of μ. Thus of the charts presented in this chapter only those in Fig. 8.5 depend upon μ, and are for $\mu = 0.45$.

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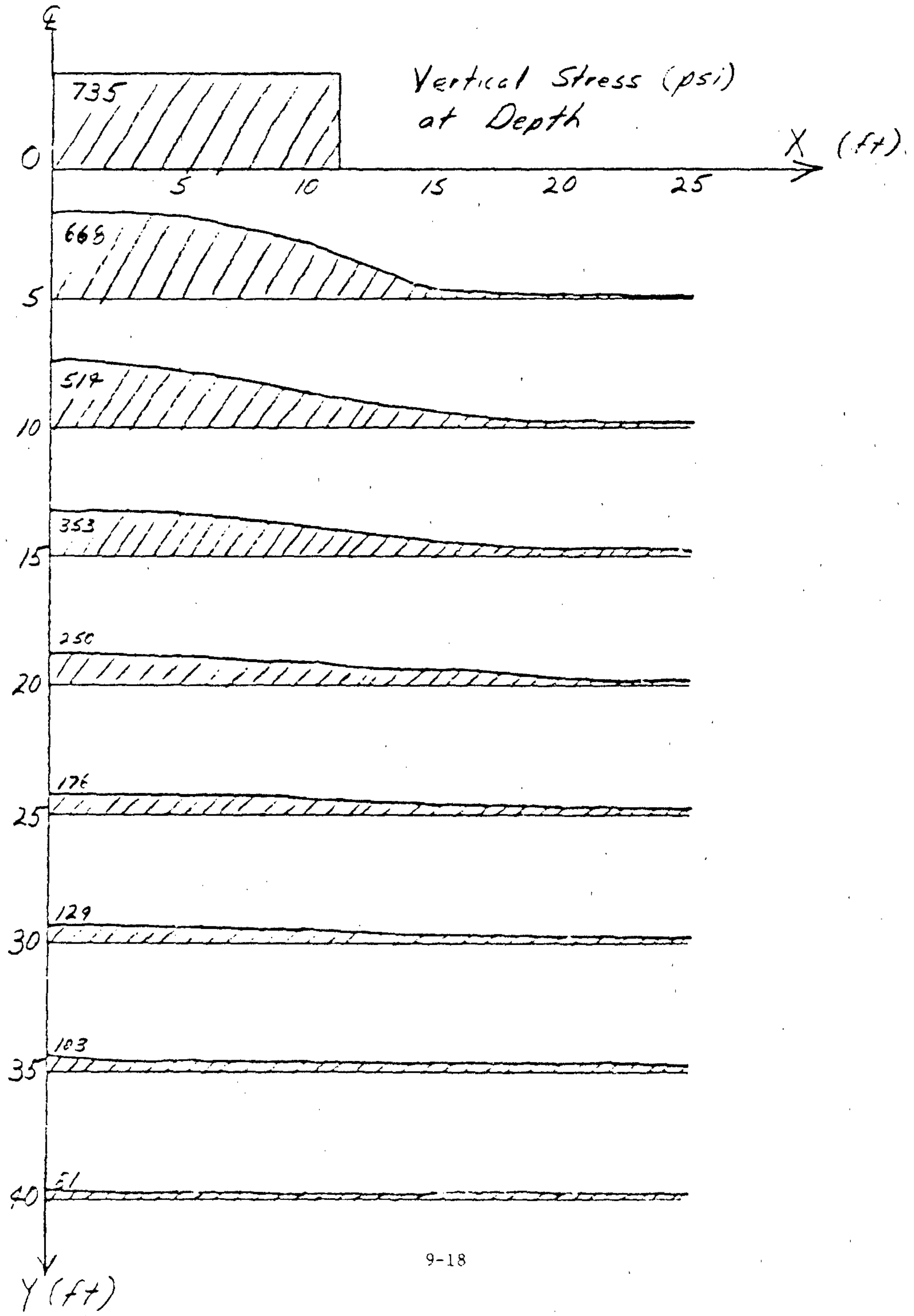
PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: Soil Pressure Attenuation
BY: [illegible] DATE: 9 Aug 19 81 CHECKED BY: DATE CHECKED: 19

9-16

5	668	632	404	73	29	22
10	514	456	294	125	44	29
15	353	323	228	125	66	33
20	250	235	183	118	66	37
25	176	169	132	95	66	44
30	129	125	103	81	59	44
35	103	95	88	66	59	44
40	81	81	66	59	51	37
45	59	59	56	51	44	33



℄
Vertical Stress (psi)
at Depth
735
0
5
10
15
20
25
X (ft)
668
5
517
10
353
15
250
20
176
25
129
30
103
35
81
40
Y (ft)

GENERAL PURPOSE BOMB

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SHEET NO. 1 OF 7

PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: Wall Damage - 500 lb Bomb
BY: [illegible] DATE: 5/29 19 82 CHECKED BY: ________ DATE CHECKED: ______ 19 ____

Worst case damage from a 500 pound bomb can be expected when the weapon detonates in contact with the wall. Breaching radius for a contact explosion can be determined from the formula[1]:

$$R = \left[\frac{W}{KC}\right]^{\frac{1}{3}}$$

where: R - breaching radius in feet
W - weight of TNT in pounds (≈ 200)
C - tamping factor (2.3 - air, 1.25 soil)
K - material factor (.5 for approximately 5' thickness reinforced concrete

$$R \text{ for untamped explosion in air} = \left[\frac{200}{(.5)(2.3)}\right]^{\frac{1}{3}} = \underline{5.6'}$$

$$R \text{ for explosion in earth} = \left[\frac{200}{(.5)(1.25)}\right]^{\frac{1}{3}} = \underline{6.8'}$$

A summary of concrete thickness required for typical placements and explosive weights is given in Figure 1.

[1] E. Cranford et al.
"Protection from Nonnuclear Weapons," AFWL-TR-70-127, February 1971, Third Printing, May 1981.

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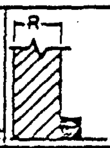
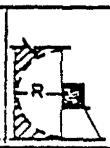
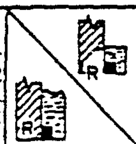
SHEET NO. 2 OF 2

PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: Wall Damage 500 lb Bomb
BY: [illegible] DATE: 6/25 19 82 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

BREACHING CHARGE WEIGHT REQUIRED TO PERFORATE REINFORCED CONCRETE SLABS [redacted]

Figure 1.

THICKNESS OF CONCRETE IN FEET	METHODS OF PLACEMENT					
	TNT (lb)					
						
2	16	28	15	8	8 / 16	1
2 1/2	31	55	28	16	16 / 31	2
3	41	67	38	21	21 / 41	4
3 1/2	59	107	55	33	33 / 59	6
4	88	159	81	49	49 / 88	8
4 1/2	126	226	116	63	63 / 126	11
5	157	282	144	79	79 / 157	16
5 1/2	208	375	192	104	104 / 208	20
6	270	486	249	135	135 / 270	21
6 1/2	344	618	316	172	172 / 344	26
7	369	664	340	185	185 / 369	33
7 1/2	454	817	418	227	227 / 454	40
8	551	991	507	276	276 / 551	49

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PROJECT NO.: 02-7092-001 SPONSOR: CERL
SUBJECT: Wall Damage - 500 lb Bomb
BY: [illegible] DATE: 6/29 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

Damage producing efficiency drops off drastically as distance between the wall and weapon increases. Data collected during and following World War II for damage to reinforced concrete wall panels was summarized and can be used to determine wall thickness required to resist breaching.[2] Damage relationships developed for detonations in air and earth are given in Figures 2 and 3 respectively. Using these relationships, thickness required to resist damage from the 500 pound bomb at various standoffs were determined and are shown in Figure 4.

"Effects of Impact and Explosion," Summary Technical Report of Division 2, NDRC, Volume I, 1946.

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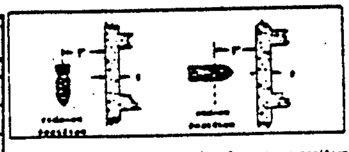
COMPUTATION SHEET

SHEET NO. 4 OF 7

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: WALL DAMAGE - 500 lb Bomb
BY: [signature] DATE: 6/29 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

DAMAGE CRITERIA ADOPTED:

DESCRIPTION OF DAMAGE	TYPE OF DAMAGE	Appr. Deflec's Span in/ft.
SLIGHT	Slight Cracking and Bending	0.1
MODERATE	Light Punching and Cracking with Possible Some Spalling	0.6
HEAVY	Heavy Punching, Shattering, or Possible Perforation	1.2
BREACHING	Perforation with Extensive Scabbing. Bars May be Bent or Twisted.	—



For contact and very near contact shots, endwise position of a bomb will cause less damage than sidewise. Figures given correspond to sidewise position, the bomb detonating not far from a point opposite center of wall. Positions appreciably offside usually result in lessened damage.

The table gives max. distance at which an air-backed reinforced concrete wall or wall panel that will experience various degrees of damage due to explosion of TNT-filled bombs in air nearby or in sidewise contact with the wall.

These data derive from tests, both model and full scale, on rectangular panels with face dimensions from 3 to 15 times the thickness. Charges used in tests ranged from about [illegible] oz. to 1700 lb. Test panels were supported along all four edges, and results showed no appreciable difference between freely supported and fixed edges.

Tests involved various degrees of reinforcing and different explosives, but all data were reduced to a basis of 1% steel by volume and bombs filled TNT. Degree of damage and ratio of central deflection to span correlate fairly well for slight, moderate and heavy damage.

Tabulated data refer to about 1% reinforcing steel by volume. For ½% steel, multiply thickness values by 0.9 for breaching and by 0.7 for other degrees of damage.

Fragments from nearby bomb detonations usually cause surface scars and a few perforations; this type of damage is not included in the present analysis.

The graph gives damage curves in terms of scale variables $r/w^{1/3}$ and $t/w^{1/3}$, where t = wall thickness (ft), r = distance from wall to bomb (ft) and w = weight of charge (lb).

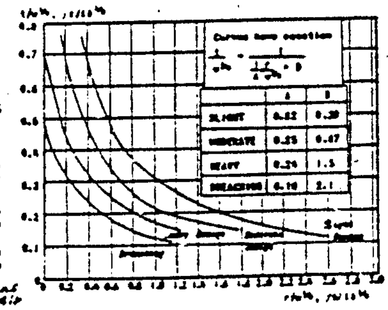
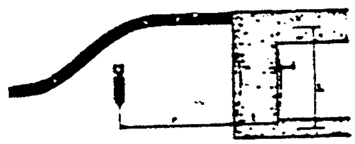


Fig 2 Explosions In Air

DAMAGE CRITERIA ASSUMED:

DESCRIPTION OF DAMAGE	TYPE OF DAMAGE: 2-edge support	TYPE OF DAMAGE: 4-edge support	d/L, in/ft
SLIGHT	Fine Cracks	Fine Cracks	0.02
MODERATE	Medium Cracks	Light Scabbing	0.1
HEAVY	Heavy Cracks and Scabbing	Severe Scabbing	0.2
BREACHING	Breached	Breached	0.5



The table gives values of the maximum distance at which various degrees of damage will result from detonation of bombs in earth. The figures given in the table apply to lightly reinforced rectangular concrete wall panels supported along either two opposite edges or along all four edges. The bomb is assumed to be approximately opposite the center of the face of the wall; any marked departure from this position will generally result in less damage. Under the same conditions the 2-edge and 4-edge supported walls will be damaged differently as described by the Damage Criteria above, but the ratio of central deflection to span is a good measure of damage for both types.

This information is based on tests of walls whose face dimensions are in the ratio of about 2:1, and whose span to thickness ratio is between 5:1 and 15:1. The test walls were reinforced with mild steel bars, about one percent by volume. Damage and central deflection were measured for bombs detonated at various distances on the earth side of the wall as shown in the sketch. Charge weights used in these tests ranged from 1/8 lb to 1000 lb.

The graph gives the ratio of central deflection to span for various wall thicknesses and charge distances in terms of the scale variables $t/w^{1/3}$ and $r/w^{1/3}$.

Tabulated values based on only meager data are given in italics. Similarly, the corresponding parts of the curves on the graph are dotted.

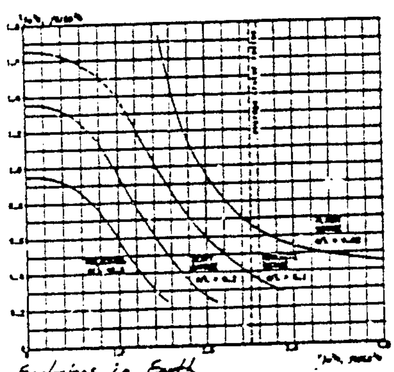


Fig 3. Explosions in Earth

SOURCES:
Tests by Ministry of Home Security and Road Research Laboratory (British) and by Committee on Fortification Design (U.S.A.)

Calculations of breaching radius for underground explosions using W.E.S. TR-SL-80-1

5/7

$$\frac{L}{W^{1/3}} = \frac{20'}{(200)^{1/3}} = 3.42$$

$\frac{t}{W^{1/3}}$	$\frac{t}{W^{1/3}}$	R (ft)	t (ft)	Free Curve
.8	.168	.98	4.6	
.6	.28	1.63	3.5	
.4	.56	3.22	2.34	
.3	.96	5.6	1.75	
.2	1.92	11.22	1.12	

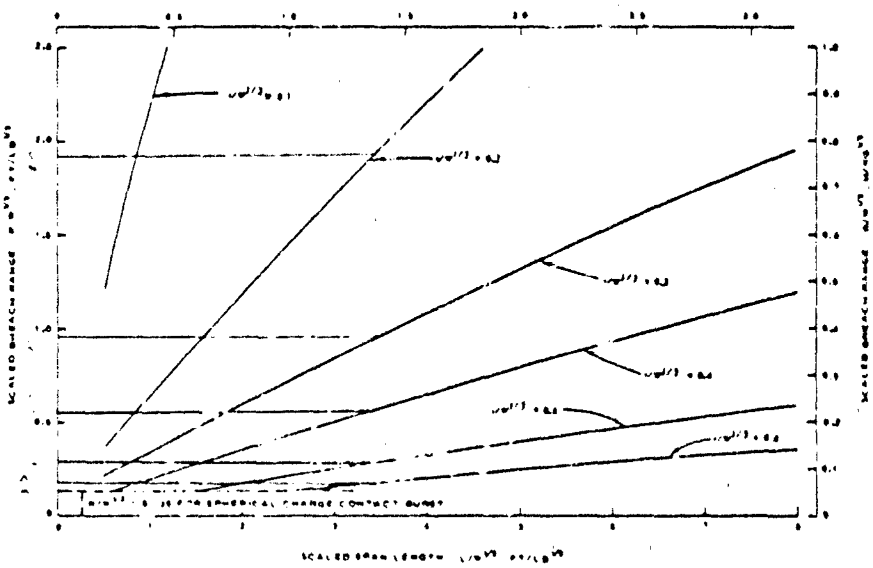


Figure 4.14 Scaled breach range—scaled span length for various scaled wall thicknesses, prototype box structures.

Ref.
Kiger, S.A. & G.E. Albritton, "Response of Buried Hardened Box Structures to the Effects of Localized Explosions," TR SL-80-1, U.S. Army Engineer Waterways Experiment Station, March 1980.

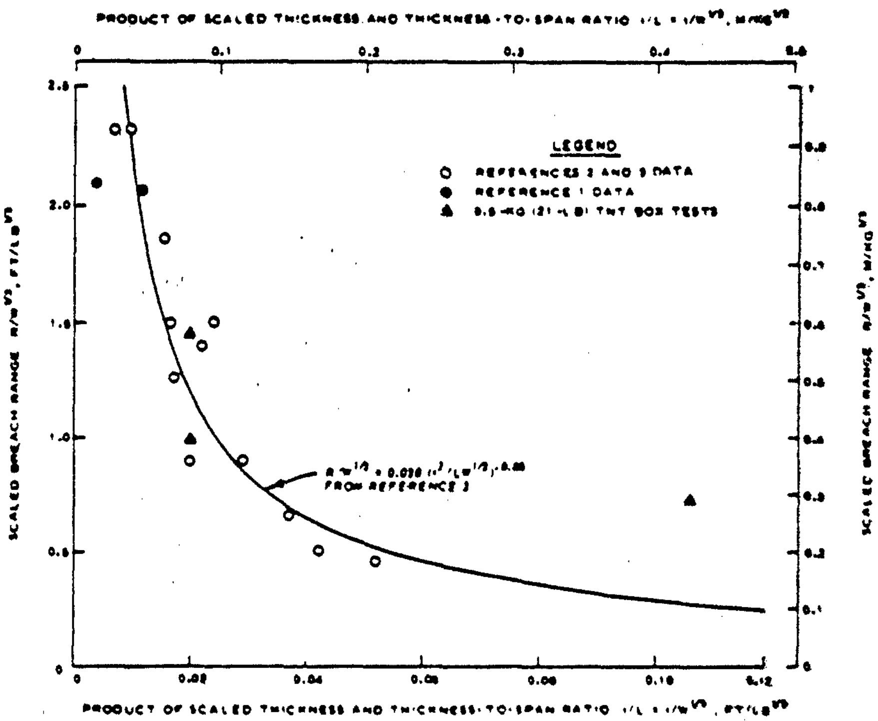


Figure 4.13 Scaled breach range-product of scaled thickness and thickness-to-span ratio for box structures.

$$\frac{\ell}{w^{1/3}} = 0.038 \left(\frac{t^2}{L w^{1/3}} \right)^{-0.88}$$

$$t = 1.6573 \left(\frac{\ell}{w^{1/3}} \right)^{-.5682}$$

Ref N.F.S. TR SL 80-1

Ref 3 [illegible], H.E., and J.W. [illegible], "Response of Buried Concrete Slabs to Underground Explosions," AFATL-TR-77-115, Sept 1977.

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SHEET NO. 2 OF 2

PROJECT NO. 02-7092-001 SPONSOR: CERL
SUBJECT: Wall Damage - See 16 Bomb
BY: [illegible] DATE: 6/29 19 82 CHECKED BY: DATE CHECKED: 19

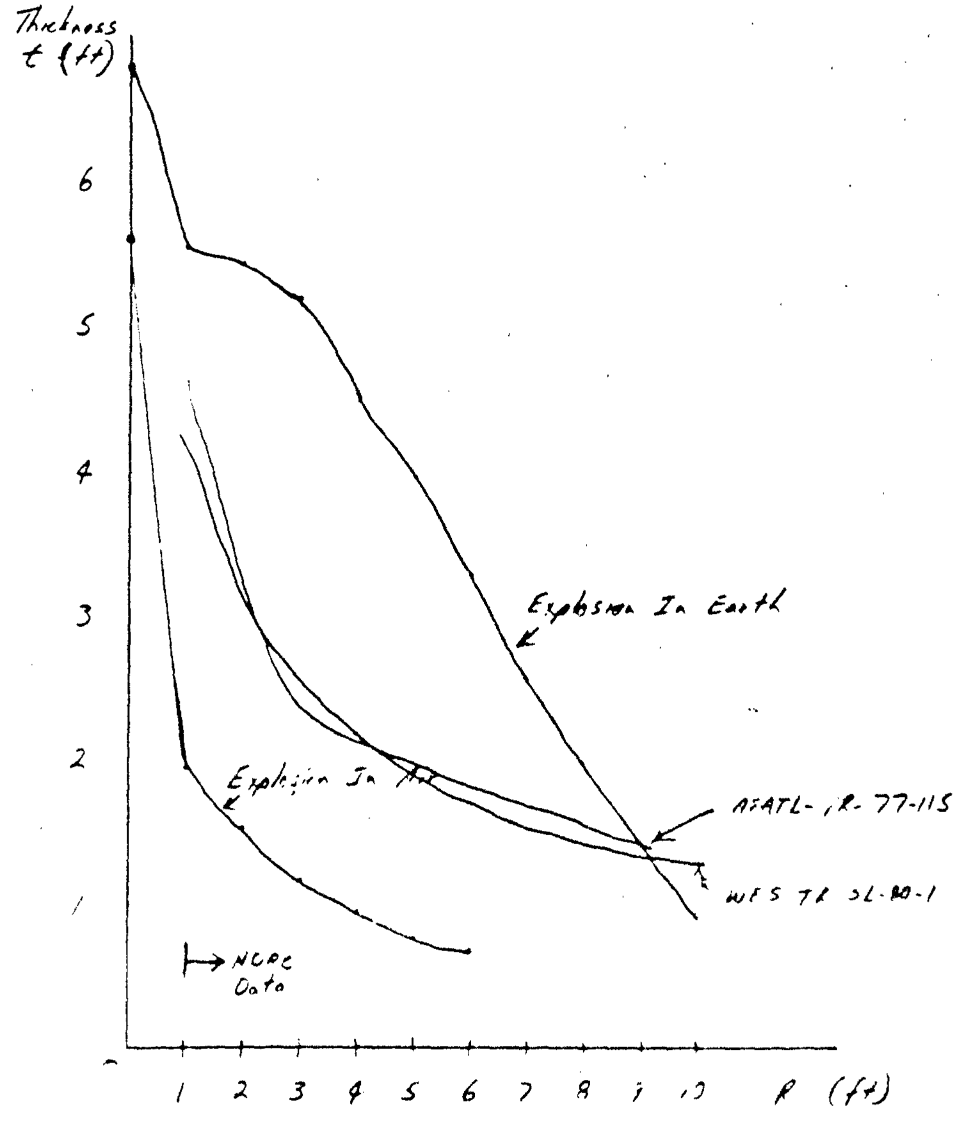

Figure 4. Thickness versus Standoff

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SHEET NO. 1 OF 6

PROJECT NO.: 02-7092 SPONSOR: CGRL
SUBJECT: PENETRATION BY 500 lb BOMB (CONCRETE & SOIL)
BY: [signature] DATE: 6/25 1982 CHECKED BY: ______ DATE CHECKED: ______ 19__

NDRC Formula (1)

$$X = KNW\left(\frac{V}{1000d}\right)^{1.8} + d \quad \text{for } \frac{X}{d} > 2.0$$

W - missile weight = 500 pounds

d - missile diameter = 14 in.

V - impact velocity = 900 feet per second

f_c' - compressive strength - 5000 psi

N - shape factor - 1.00 average bullet nose

$K = \frac{180}{\sqrt{f_c'}}$ - penetrability factor = $\frac{180}{\sqrt{5000}} = 2.546$

$$X = 2.546\,(1.00)(500)\left(\frac{900}{1000\,(14)}\right)^{1.8} + 14 = 23 \text{ in.} \cong 2'$$

Weapon Data for penetration into reinforced concrete and soil are given in Figures 1 and 2 respectively.(2) Concrete thicknesses greater than approximately 29" are expected to resist penetration by the 500 pound bomb. Soil thickness of 15 feet can also deny penetration. Concrete thickness can be decreased when combined with soil overburden, or additional layers of concrete protection (burster slabs).

(1) Sliter, G.E., "Assessment of Empirical Concrete Impact Formulas," ASCE Journal of the Structural Division, May 1980.
(2) "Effects of Impact and Explosion," Summary Technical Report of Division 2, NDRC, Volume I, 1946.

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SHEET NO. 2 OF 6

PROJECT NO.: 02-7042-001 SPONSOR: CERL
SUBJECT: Concrete Perforation (500 lb Bomb)
BY: Phillip T. Nash DATE: 21 Apr 1982 CHECKED BY: ______ DATE CHECKED: ______ 19 ___

Perforation

NDRC – $\frac{x}{d} = \frac{23}{14} = 1.64$

$$\frac{t_p}{d} = 1.32 + 1.24\frac{x}{d}$$

$$t_p = 14\{1.32 + 1.24(1.64)\} = 46.95''$$

~~Modified~~

CEA - EDF

$$t_p = .765\,(f'_c)^{-\frac{3}{8}}\left(\frac{W}{d}\right)^{\frac{1}{2}} V^{\frac{3}{4}}$$

$$= .765\,(5000)^{-\frac{3}{8}}\left(\frac{500}{14}\right)^{\frac{1}{2}}(900)^{\frac{3}{4}}$$

$$= .765\,(.041)(5.976)(164) = 30.8''$$

The above formulas were used to determine the thickness of concrete required to resist perforation by a 500 lb bomb. The formulas apply to air backed concrete, soil backed concrete will require less thickness.

Reference: Sliter, G.E., "Assessment of Empirical Concrete Impact Formulas," ASCE Journal of the Structural Division, May 1980.

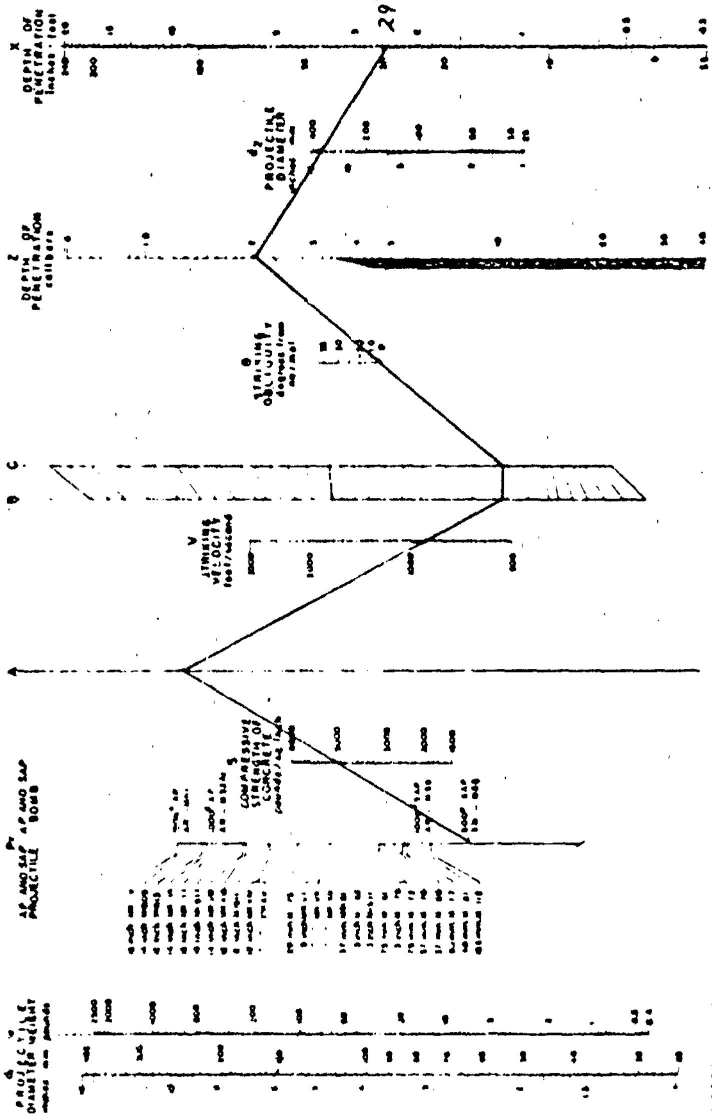
Figure 1.

WEAPON DATA

9A1 CONCRETE PENETRATION

PENETRATION OF REINFORCED CONCRETE BY AP PROJECTILES AND AP AND SAP BOMBS

BASED ON DATA DEVELOPED FOR THE CHIEF OF ENGINEERS



DIRECTIONS: Determine the diameter and weight of that part of the projectile which penetrates the slab. (The total weight minus the weight of the windshield will usually be correct.) Draw a line through the proper points on the d_1 scale and w scale at the left of the chart to the Pr scale. (If the projectile is a type listed on this scale, the above may be omitted.) Continue from the point through the S scale to the A scale. From the A scale draw a line through the V scale to the B scale and follow the guide lines to the C scale. From the C scale draw a line through the θ scale to the Z scale. (If the point falls within the shaded area the projectile will probably stick in the target.) From the Z scale draw a line through the d_2 scale and read the depth of penetration from the X scale. For oblique fire this depth is the maximum penetration normal to the target face. If the projectile or bomb causes scabbing (see 2B-sheet 1) the penetration will be somewhat more than shown here. The penetration for oblique fire at velocities above 2000 ft/sec may be somewhat more than shown here.

EXAMPLE: The dotted line shows a 6 inch, 100 pound projectile striking 4,000 psi concrete with a velocity of 1,800 ft/sec at an obliquity of 20°. The projectile will penetrate to a depth of 49 calibers or 29.4 inches. The projectile will probably stick in the target.

ACCURACY: This chart gives results accurate within 15%.

June 1943

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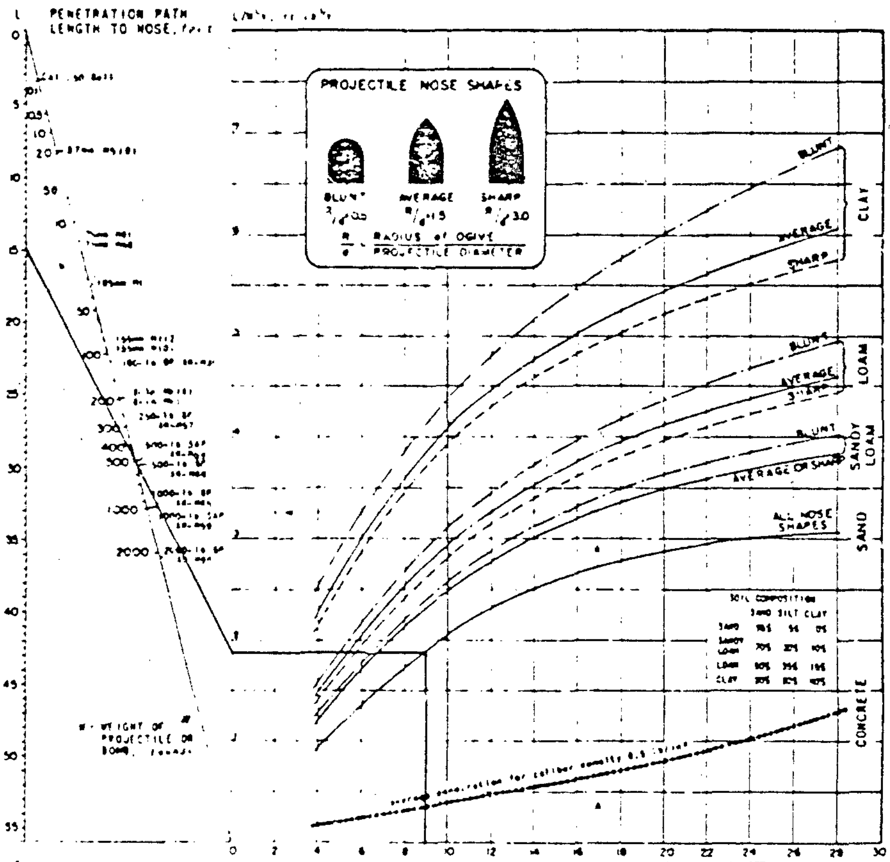
Figure 2.

2 A2* SOIL PENETRATION

PENETRATION OF BOMBS AND PROJECTILES INTO SOIL

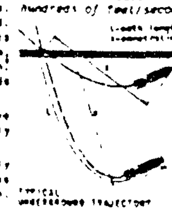
15'



The graph and nomogram give the relation between striking velocity and penetration path length, measured to the nose, for projectiles or bombs of various weights penetrating into several soils. Curves marked blunt, average, and sharp are for projectiles of different nose shapes as sketched. Where no appreciable effect of nose shape on penetration has been observed only a single curve is drawn. The dependence of penetration path length on projectile weight, as given by the nomogram, agrees with observations for projectiles or bombs having caliber densities from 0.15 to 0.65 lb/in.³ Most bombs and artillery projectiles have caliber density values (weight of projectile in pounds divided by the cube of the diameter in inches) within the above range.

Trajectories in soils are usually straight for two-thirds or more of the path length, but curve near the end of the path (see sketch). For this reason final distance from the surface is usually 10% to 30% less than the penetration path given here.

Curves given are for average soil types. Penetrations into rich plastic clay are approximately 30% greater than those observed in clay. The dotted curve at the bottom of the graph gives average penetration into good quality reinforced concrete, and is added here for rough comparison.



EXAMPLE: The dotted line shows that a projectile of average nose shape and weight of 50 lb striking sandy loam soil with a velocity of 1700 ft/sec will have a path length of approximately 12.5 ft, measured to the nose. Because of the curvature of the underground trajectory, the actual penetration from the surface will be somewhat less.

SOURCE: British and American tests with bombs and large caliber projectiles at velocities below 1100 ft/sec. Small caliber tests for the Corps of Engineers, U.S.A. extending over entire velocity range. The curves agree with measurements to ±20%.

* Revision of 2 A2 dated September 1944

FTM No. 173 February 1945

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SHEET NO. 5 OF 6

PROJECT NO.: 02-7052-001 SPONSOR: CERL
SUBJECT: Penetration of Soil by 500 lb Bomb
BY: Shirley T. Neal DATE: 2/12 19 82 CHECKED BY: DATE CHECKED: 19

Ref. Young, C. Wayne, "Depth Prediction for Earth-Penetrating Projectiles," Journal of the Soil Mechanics and Foundations Division, ASCE, May 1969.

Young's formula was used as another method to determine penetration of the 500 lb bomb into soil.

$$Z = 0.0031\ S\ N \left(\frac{W}{A}\right)^{\frac{1}{2}} (V-100)$$

Z - penetration depth (ft)

S - Soil Constant = 7

N - Nose Constant = 1.22

W - Weight = 500 lb

A - area = 153.9 in^2

V - impact velocity = 900 ft/sec

Z = 38 ft.

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SHEET NO 6 OF 6

PROJECT NO.: 02-7092-001 SPONSOR: CEPL
SUBJECT: Penetration of Rock Rubble Overlay
BY: [illegible] DATE: 6/29 19 83 CHECKED BY: ______ DATE CHECKED: ______ 19 ____

Lexington Penetration Formula (1) (Rock)

$$KE = \frac{1}{2g} W V^2 \qquad W = 500 \text{ lb},\ V = 900 \text{ fps},\ g = 32.2$$

$$= \frac{1}{2(32.2)} 500 (900)^2 = 6.2888 \times 10^6 \text{ ft-lbs}$$

$$N_R = \frac{1-m_1}{2.484 m_1} \cdot \frac{N}{d} Q_{NR}$$

Q_{NR} (from design chart Fig 203) = 1.6

$m_1 = .25$

$d = 1.2$ feet

N = (from Fig 199) = 1.0 ?

$$N_R = \frac{1-.25}{2.484(.25)} \frac{1.0}{1.2} 1.6 = \underline{\underline{1.61'}}$$

Research has shown that projectiles encountering at least two layers of rock rubble at least the diameter of the projectile have a high probability of being defeated.(2) The Lexington formula showed 1.61 feet of granite can stop the threatening 500 pound bomb. It is reasonable that two layers of 14 inch diameter granite boulders can accomplish the same or equal effect.

(1) Lexington, C.W. and Smith, E.L. "Bomb Penetration Project," Colorado School of Mines Research Foundation Inc., Golden Colo. 15 June 1951.
(2) Shielding Methodology for Conventional Weapons," USWES, Jan 1980.

LARGE HIGH EXPLOSIVE CHARGE

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COMPUTATION SHEET

SHEET NO. 1 OF 1

PROJECT NO.: 02-7092 SPONSOR: CERL
SUBJECT: 300,000 LB HE @ 100 M
BY: E MORRIS DATE: ______ 19 ______ CHECKED BY: ______ DATE CHECKED: ______ 19 ______

ASSUME THAT THE 300,000 # CHARGE IS ON THE GROUND SO THE EFFECTIVE CHARGE WEIGHT IS 2×300,000 = 600,000 LB.

DISTANCE = 100 M = 328 FEET

SCALED DISTANCE = $\frac{R}{W_e^{1/3}} = \frac{328}{(600,000^{1/3})} = 3.9$ FT/LB$^{1/3}$

PER DOE/TIC - 11268,

$P_{SIDE-ON} = 42$ psi

$i_{SIDE-ON} = .01250\ W^{1/3} = .0125\,(84.3) = 1.05$ PSI-SEC

$T_{S-O} = \frac{2i}{P} = \frac{2(1.05)}{42} = .05$ SEC

$P_{REFL} = 190$ psi

$i_{REFL} = .039\ W^{1/3} = 3.3$ PSI-SEC

$T_{REFL} = \frac{2i}{P} = \frac{2(3.3)}{190} = .035$ SEC

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